Brahma Singh
Pritam Kalia *Editors*

Vegetables for Nutrition and Entrepreneurship

Springer

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Editors
Brahma Singh
Brahma Singh Horticulture Foundation (BSHF)
New Delhi, India

Pritam Kalia
ICAR-Indian Agricultural Research Institute
New Delhi, India

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Dedicated to

In loving memory of our most revered Late Professor Dr. Kirti Singh—A legend Vegetable Scientist of India, who we lost recently. He was very happy and supportive of our webinar series on horticultural crops we started under the aegis of Brahma Singh Horticulture Foundation (BSHF) during pandemic in 2020 focusing on vegetable nutrition and entrepreneurship. He had always been appreciative of our efforts in advancing vegetable science pursuits.

Preface

Nutrition plays a key role in our daily life. Its value is more important for any individual's health. The solid food or liquids affect our body and health because each of these contains particular nutrition which is very necessary for our physical and mental growth. Whenever we take any food or nourishing liquids, our body digests and absorbs the simple but essential minerals, vitamins, fats, proteins, carbohydrates, fats, and water from these food or nourishing liquids and converts them into bloodstream and energy that help our body to grow and keep it healthy and build new cells in our body. Nutrition promotes vitality and an overall sense of health and well-being by providing the body with energy and nutrients that fuel growth, healing, and all body systems and functions. Good nutrition will also help to ward off the development of chronic diseases. Fresh food provides the body with what it needs to produce energy, promote metabolic activity, prevent micronutrient deficiencies, ward off chronic disease, and promote a sense of overall health and well-being.

Vegetables which encompass fresh edible portions of certain herbaceous plants, such as roots, stems, leaves, flowers, fruits, pods, etc., are either eaten fresh or prepared in a number of ways, usually as a savory. All the important vegetables were cultivated among the ancient civilizations of either the Old or the New World and have long been noted for their nutritional importance. Vegetables have water content in excess of 70%, with only about 3.5% protein and less than 1% fat. These are good sources of minerals, especially calcium and iron, and vitamins, principally A and C. Nearly all vegetables are rich in dietary fiber and antioxidants and are referred to as protective foods. Fresh vegetables are naturally low in fat, salt, and sugar, making them an excellent food choice. They provide energy, vitamins, minerals, and fiber, and there is growing evidence of additional health benefits from a range of phytonutrients, which are naturally occurring plant compounds. There are thousands of these different phytonutrients in vegetables, usually in small amounts. Plants produce them for their own protection from insects or bacteria, as pigments for photosynthesis (energy production) and flavor. They are often responsible for the bright colors of fruits and vegetables, and research shows that these compounds may help reduce the risk of disease and promote health. Few examples of phytonutrients worth citing are lycopene in tomatoes, beta-carotene in carrots, and glucosinolates in Cole vegetables.

Phytonutrients may work in lots of different ways to protect against diseases and promote health. Modes of action that are being investigated include anti-inflammatory activity, boosting the body's antioxidant defenses, modulating gut microflora, lowering cholesterol, fighting bacteria, and supporting the body's immunity. Vegetables are important for human nutrition in terms of bioactive nutrient molecules such as dietary fiber, vitamins, and minerals, and non-nutritive phytochemicals (phenolic compounds, flavonoids, bioactive peptides, etc.). These nutrient and non-nutrient molecules reduce the risk of chronic diseases such as cardiovascular diseases, diabetes, certain cancers, and obesity.

Since vegetables have been instrumental in minimizing nutritional deficiencies at household level, they have special mention in sustainable development goals (SDGs) of Food and Agriculture Organization (FAO) for their role as a source of dietary micronutrients and income at the global level. Vegetable farming can be a big entrepreneurship opportunity for small and marginal farmers. These farmers with less than two hectares of land account for 86.2% of all farmers in India, but own just 47.3% of the crop area, according to provisional numbers from the 10th agriculture census of 2015–2016. The presence of a significant number of small and marginal farmers, close to 126 million according to a recent survey, is notable, who on an average have land holding of just 0.6 ha each. In small farms, vegetable crops offer the best options for achieving high yields from multiple harvests across number of crops in a year when combined with the use of modern technologies and access to markets. This can go a long way in sustaining families of small farmers.

Entrepreneurship is the process of turning a concept into a developed product. To understand the importance of entrepreneurship, recognizing what an entrepreneur does is necessary. The term itself comes from the French "entreprendre," which means "to undertake." An entrepreneur is someone who undertakes or plans for all the risks and responsibilities that come with the formation of a new business to earn profits. Entrepreneurship is important because it has the benefits like creation of job opportunities, creation of new businesses, innovation, leads to better standards of living, supports research and development, promotes community development, and leads to increased productivity and creation of national wealth. It contributes to social welfare.

Alongside these basics, it is important to go ahead with vegetable quality improvement to meet global requirements emerging due to the current evolution of consumers' demands. In particular, producing vegetables with enhanced nutritional and organoleptic quality is one of the most challenging targets for breeding, facing climatic changes and the need for a more efficient production system. High-throughput metabolomic, transcriptomic, and genomic advances and others represent useful tools to identify genetic architecture and biochemical pathways and also to predict breeding values for selection and deployment. Modern breeding needs to address global challenges including climate change, varieties, and hybrids amenable to emerging modern production technologies, increasing yield and quality to secure food and nutritional security for a growing population as India (1.4286 billion) has just scaled beyond most populous China (1.4257 billion) in 2023 and will participate in maximizing the resources of farming systems. Current tools in multiomic approaches are a fundamental support for vegetable breeding to match crop metabolism genetics and further improve organoleptic and nutraceutical quality in new varieties. Advances in -omics technologies make it possible to elucidate the genetic and molecular bases of the multiple traits composing quality using genetic, genomic, and metabolomics approaches, particularly in case of pleiotropy and unfavorable trait association. The application of CRISPR/Cas in tomato breeding, for instance, has hastened improvement, and similar technology could fasten breeding, reducing the gap with other vegetable crops.

With this backdrop, the first webinar series was organized on Vegetable Nutrition and Entrepreneurship by Brahma Singh Horticulture Foundation (BSHF) during 2020–2021. The program was designed to bring together researchers from diverse fields such as vegetable crops, production systems, bioactive compounds, genetic resources, regions, underexploited crops, value addition, etc. to highlight their increasing importance. The 22 chapters in this book represent a collection of recent and highly relevant reviews, covering a wide range of topics, prepared by speakers in the aforementioned webinar series who are well-recognized experts in their respective fields.

We thank all the contributing authors profusely for their untiring efforts in developing excellent informative reviews on vegetable nutrition and entrepreneurship. We, the editors, hope that this book will provide a valuable reference resource as also inspiration for new researchers, teachers, students, planners, entrepreneurs, progressive farmers, health conscious consumers, pharmaceutical and cosmetic industry owners.

Finally, we are also thankful to the publisher for their support, inputs, and agreeing to bring out this important publication.

New Delhi, India

Brahma Singh
Pritam Kalia

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About the Editors

Brahma Singh PhD (Horticulture), is a Padma Shri Awardee—the fourth highest Indian Civilian Award. He is a Fellow of NAAS, NABS, IAHS, ISVS, AFST(I), BVd, ISNS, and Hon. FISAE. Prof. Singh is the Founder Chairman, Prof. Brahma Singh Horticulture Foundation, Delhi; Founder President, Indian Society for Protected Cultivation, New Delhi; President, Indian Society of Vegetable Science, Varanasi; Former President of Society for New Age Herbals; and Member, Planning Board, Ladakh UT. He had the privilege to work under Dr. APJ Abdul Kalam, former President of India, both in DRDO and at President House, New Delhi. He is known for his contributions to the greening of Leh valley—a cold Himalayan desert—protected horticulture in the country, and exploitation of natural growth of sea buckthorn/Brahmphal in Ladakh UT, besides developing root-knot nematode varieties of tomato and several varieties of different vegetables suitable for higher Himalayan region. He has been the organizer of BSHF series of webinars since the last 2 years. A monograph on Life Sciences Research in DRDO for the Service of Soldiers has been released, which is compiled by Prof. Singh. (For details, Google Wikipedia/Brahma Singh).

Pritam Kalia A renowned vegetable breeder, who headed the Vegetable Science Division, at the ICAR-IARI, New Delhi, for more than 6 years and contributed significantly to the overall modernization of the division. Besides, Dr. Kalia served as Professor of Horticulture at ICAR-IARI handling academics of four diverse divisions. He also served as ICAR-Emeritus Scientist for full term and worked on a very important futuristic topic entitled “Advances in biotic stress resistance breeding and β-carotene biofortification in Indian cauliflower and nutraceutical mapping in carrot.” Dr. Kalia developed 33 varieties of different vegetable crops with major contributions in exotic vegetables, nutraceutical and resistance breeding, and genetic mechanisms facilitating hybrid breeding in cauliflower and carrot. He is credited with the introduction of new vegetable crops in India such as broccoli and leek, developing their indigenous varieties and popularizing them. He identified genes *Xca1bo* and *Xca1bc*, which impart resistance to black rot disease in cauliflower. These are being bred into commercial varieties through marker-assisted backcross breeding. Dr. Kalia has introgressed beta-carotene-enhancing *Or* gene in Indian cauliflower, which will go a long way in tackling beta-carotene malnutrition problem in India. For his outstanding contribution to vegetable science, he was awarded the VASVIK Award, IAHS Shivshakthi Lifetime Achievement Award, and Rafi Ahmed Kidwai Award of the ICAR.

1 Nutritional Enhancement of Vegetable Crops (With Major Emphasis on Broccoli: A New Cole Crop in India)

Pritam Kalia and Shrawan Singh

Abstract

Vegetables are an essential component of balanced diets for good health. They are 'protective foods' as they are rich in micronutrients, vitamins, antioxidants and other health-benefiting compounds. Hence, intake of adequate quantity of quality-rich vegetables is essential. Although vegetables are known to be a treasure of microelements, they also contain appreciable amount of major nutrients such as protein, carbohydrates, ash and dietary fibres, thereby contributing to the overall nutrition and health factors of a balanced diet. These crops are known as a good source of nutraceuticals, which are gaining popularity among consumers and also have a significant presence in the market. Nutraceutical is any substance that may be considered as food or part of a food and provides medical or health benefits, encompassing prevention and treatment of diseases. Research efforts strive to improve our understanding of crop manipulations for nutrition, and in many cases, substantial progress has been made by using conventional and molecular tools. Cole vegetables, such as cabbage, broccoli, Brussels sprouts and cauliflower, are rich sources of anticancerous sulphur-containing glucosides and bioactive compounds known as glucosinolates. Broccoli is high in vitamin C and soluble fibre and contains multiple nutrients with potent anticancerous properties, including di-indolylmethane and selenium. The 3,3′-di-indolylmethane found in broccoli is a potent modulator of the innate immune response system with antiviral, antibacterial and anticancer activity. It also contains the compound glucoraphanin, which can be processed into the anticancerous compound sulphoraphane. Intake of broccoli has been found to reduce the risk of prostate cancer. Genetically, most of the quality traits are complex in nature; therefore, limited success has been made through

P. Kalia (✉) · S. Singh
ICAR-Indian Agricultural Research Institute, New Delhi, India

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conventional breeding of nutrient-dense varieties in vegetable crops. But modern high-throughput biochemical and molecular analytical tools and techniques have a great potential to handle complex traits with shortened breeding cycles.

Keywords

Nutrients · Nutraceuticals · Phytonutrients · Carotenoids · Anthocyanins · Glucosinolates · Cole crops · Cauliflower · Cabbage · Broccoli · Brussels sprouts · Knol khol · Kohlrabi · Kale

1.1 Introduction

Vegetables are one of the essential components of balanced diets for good health. Vegetables are 'protective foods' as they are rich in micronutrients, vitamins, antioxidants and other health-benefiting compounds. Hence, intake of adequate quantity of quality-rich vegetables is essential. Notably, a number of epidemiological evidences indicate association between diet rich in vegetables and decreased risk of many non-communicable diseases. The beneficial health effects of vegetables are not only due to minerals and vitamins but also due to a diverse range of antioxidant compounds such as carotenoids in leafy (spinach, beet leaf, amaranth, coriander leaf, kale, etc.) and orange-colour vegetables (orange carrot, pumpkin, orange cauliflower, orange flesh sweet potato, cassava, etc.), anthocyanin in purple- or red-colour vegetables (beetroot, black carrot, red amaranth, red cabbage, purple broccoli and purple cauliflower, purple lettuce, etc.), lutein in pale or yellow vegetables (pale carrot), lycopene in red-coloured vegetables (tomato, watermelon, red radish, seed coat of bitter gourd, and *Momordica*), glucosinolates in radish and cole vegetables, quercetin and fructan in onion, anti-diabetic constituents in bitter gourd and white brinjal, etc. Increasing health issues on one side and simultaneous increase in information on healthy foods on the other are attracting people towards consumption of fruits and vegetables. There is increased global interest in nutraceuticals and edible colour because of their positive appeal to sensory organs for consumption and their immediate role in human health. Further, these are natural origin colours; hence, their demand is increasing in the food industry, particularly organic food industry.

Besides yield- and stress-related traits, the quality traits are getting adequate attention in vegetable breeding programmes. Consumer awareness for nutritional and health concerns also leads to changes in consumer preference in favour of quality vegetables, which stresses on breeding varieties rich in such novel traits. However, quality of food has multi-dimensions, which depend not only on the property of food but also on consumer perception (Fig. 1.1). Genetically, most of the quality traits are complex in nature; therefore, limited success has been made through conventional breeding for breeding nutrient-dense varieties in vegetable crops. But modern high-throughput biochemical and molecular analytical tools and

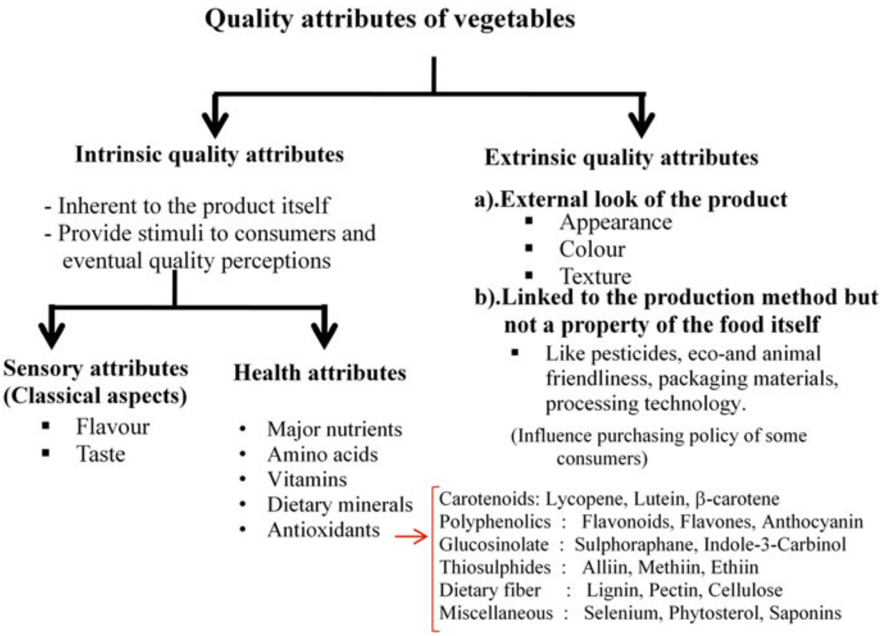


Fig. 1.1 Quality attributes of vegetable crops

techniques have great potential to handle complex traits with shortened breeding cycles.

1.2 Dietary Nutrients and Health Attributes of Vegetables

Vegetables are important sources of proteins, vitamins, minerals and health-benefiting phytochemicals. They are low in fat and calories and devoid of cholesterol. Vegetables are rich in protein, which is essential for body building, mainly tissue, muscles and blood such as garlic, garden pea and other legume vegetables. These are a good source of potassium, which helps in maintaining healthy blood pressure and reducing the development of kidney stone. Examples are sweet potato, beans, tomato products, beet leaf, spinach, etc.

Vegetables are rich in dietary fibre to reduce blood cholesterol level, lower risk of heart diseases and improve bowel function. Examples are cowpea, hyacinth bean, drumstick, pointed gourd, etc. Vegetables are also rich in folate, which helps the body to form red blood cells. Examples are spinach, beet root, cabbage, broccoli, Brussels sprouts, etc. Rich profile of vegetables for beta-carotene makes them a good candidate food for keeping the eyes and skin healthy. Beta-carotene helps to protect against infections. Examples are amaranth, beet leaf, carrot, pumpkin, muskmelon, tomato, etc. Vitamin C-rich vegetables are broccoli, tomato, cauliflower, cabbage and chilli, which help heal cuts and wounds and keep teeth and gums healthy.

Vegetables are also rich in different phytochemicals or bioactive compounds, which have protective and disease-preventive roles. Examples are cole crops in glucosinolates; tomato, carrot and watermelon in lycopene; carrot and beet root in anthocyanin and betacyanin, respectively.

1.3 Major Nutrients in Vegetable Crops

Vegetables are known to be a treasure of microelements, but they also contain appreciable amount of major nutrients such as protein, carbohydrates, ash and dietary fibres, thereby contributing to the overall nutrition and health factors of a balanced diet. There is wide difference in content values for these elements, and most of the commercially grown and widely consumed vegetables have less content. On the other side, the minor or underexploited vegetables appear to be a rich source of these elements as shown in Table 1.1.

Table 1.1 Major dietary mineral content in edible portion of common and underutilized/minor vegetable crops

Content	Major vegetables	Minor vegetables
Protein (g/100 g)	Peas (7.25 ± 1.03), French beans (2.49), cauliflower (2.15), brinjal (1.48), tomato (0.76), capsicum (1.47), bitter gourd (1.61), potato (1.54), carrot (1.04), radish (0.77), sweet potato (1.33), colocasia (3.31), okra (2.08), lettuce (1.54), fenugreek leaves (3.68)	Agathi leaves (8.01), green amaranth leaves (3.29), red amaranth leaves (3.93), Brussels sprouts (4.26), drumstick leaves (6.41), garden cress (5.62), mustard leaves (*Brassica juncea*) (3.52), parsley (5.55), pumpkin leaves (4.21), cluster beans (3.55), field beans (3.71), drumstick pod (2.62), *Alternanthera sessilis* (5.29), pak choi leaves (1.41), colocasia leaves (3.42), beet greens (2.38), bathua leaves (2.50), lotus roots (1.94)
Ash (g/100 g)	Radish (0.82), sweet potato (0.96), potato (0.92), carrot (1.22), colocasia (1.95), okra (0.94), brinjal (0.70), bottle gourd (0.36), bitter gourd (0.81), spinach (2.47), lettuce (1.11), tomato (0.43)	Pumpkin leaves (2.24), Alternanthera sessile (2.65), parsley (2.25), pak choi leaves (1.10), colocasia leaves (2.30), beet green (2.69), amaranth leaves (2.52), Basella leaves (1.09), bathua leaves (1.71), lotus roots (1.50)
Dietary fibre (g/100 g)	Tomato (1.58), okra (4.08), peas (6.32), cauliflower (3.71), capsicum (2.19), cluster bean (4.83), brinjal (3.98), bottle gourd (2.11), bitter gourd (3.49), spinach (2.38), lettuce (1.79), cabbage (2.76), Brussels sprouts (4.29), potato (1.71)	Ash gourd (3.37), pumpkin leaves (2.25), parsley (3.87), mustard leaves (3.92), drumstick leaves (8.21), colocasia leaves (5.60), beet green (3.64), bathua (4.01), amaranth leaves (4.41), lotus roots (4.70)

1.4 Nutraceuticals from Vegetables

Vegetable crops are known as a good source of nutraceuticals, which are gaining popularity among consumers and also have significant presence in the market. The term “nutraceutical” was coined by Dr. Stephen DeFelice in 1989, founder and chairman of the Foundation for Innovation in Medicine in 1989. According to DeFelice, ‘a nutraceutical is any substance that is a food or a part of a food and provides medical or health benefits, including the prevention and treatment of disease’. The word nutraceutical represents a combination of two words, i.e. ‘nutrient’ (a nourishing food or food component) and ‘pharmaceutical’ (a medical drug), and the intended meaning is quite evident, even if these terms encompass very different product categories. Nutraceutical is any substance that may be considered as food or part of a food and provides medical or health benefits, encompassing prevention and treatment of diseases. They are also referred to as a product isolated or purified from foods and generally sold in medicinal forms not usually associated with food and demonstrated to have a physiological benefit or provide protection against chronic diseases. On the other hand, nutraceuticals not only maintain, support and normalize any physiologic or metabolic function, but can also potentiate, antagonize or otherwise modify physiologic or metabolic functions for good health. These are available in various forms such as pills, capsules, solutions, gels, liquors, powders and granulates. A nutraceutical may be a single natural nutrient in powder or tablet form (i.e. lycopene, protein) or a source of different elements (i.e. multivitamin and mineral tablets, powder). These are not necessarily a complete food, but equally not a drug. The nutraceuticals have received considerable interest because they are presumed to be safe for health and with potential nutritional and therapeutic effects (Dureja et al. 2003). In general, the definition of nutraceuticals is supplemented with five broad categories that encompass the full range of nutraceuticals. These are:

1. Raw food, e.g. carrots that contain beta-carotene
2. Processed foods without added ingredients, e.g. oat bran cereal
3. Processed foods with added ingredients, e.g. calcium-enriched orange juice
4. Genetically engineered foods, e.g. enhanced tomato with higher concentrations of lycopene
5. Isolated/purified preparations of active ingredients sold in tablet, capsule or tincture form

There are different nutraceuticals/bioactive compounds in different vegetable crops having varied health benefits as given in Table 1.2.

1.4.1 Global Scenario of Nutraceuticals

The world market for functional foods and beverages is highly dynamic. Globally, the nutraceutical product market in 2019 was around USD 247 billion, which was

Table 1.2 Vegetables rich in nutraceuticals

Nutraceuticals/ bioactive compounds	Putative biological effect	Vegetables
Allyl sulphides, organosulphur compounds, allicin, quercetin	TC and LDL-C, TG, cholesterol and FA synthesis, BP, thrombosis, AOx, carcinogen detoxification, tumour promotion, modulation of cell signalling pathways, inhibition of COX-2	Allium vegetables (garlic, onions, chives, leeks)
Indoles/ glucosinolates, sulforaphane Isothiocyanates/ thiocyanates, thiols Isothiocyanates	Tumour initiation/promotion, carcinogen activation, carcinogen detoxification Induction of phase II enzymes, modulation of cell signalling pathways, induction of apoptosis	Cruciferous vegetables (broccoli, cauliflower, cabbage, Brussels sprouts, kale, turnips, kohlrabi) Broccoli
Lycopene	LDL-C and LDL-C oxidation, AOx, antimutagen	Solanaceous vegetables, (tomatoes, peppers)
Capsaicin	Modulation of cell signalling pathways, inhibition of phase I enzymes	Chilli
Carotenoids, phthalides Polyacetylenes	Promote the activity of white cells and act as anti-carcinogenic	Umbelliferous vegetables (carrots, celery, parsley, parsnips)
Flavonoids (isoflavones)	Carcinogen detoxification	Beans
Heart disease; cancer	TC and LDL-C, LDL-C oxidation, TG, thrombosis, AOx, antimutagen, angiogenesis HDL-C, apoptosis	Soybean
Vitamin A (retinol)	Anti-carcinogenic, combined opsin to give rhodopsin for better vision	Carrots, squash, broccoli, sweet potatoes, tomatoes, kale, collards, cantaloupe and pumpkin
Vitamin C (ascorbic acid)	Anti-carcinogenic	Green peppers, broccoli, green leafy vegetables, cabbage and tomatoes
Vitamin E	Antioxidant	Green leafy vegetables
Coumarins, steroids, alpha-tocopherol	Anti-diabetic	Fenugreek
Peptides, terpenoids	Macular degeneration	Bitter gourd
Flavonoids (saponins)	Protect against cancer, lower cholesterol	Beans
Indoles, isothiocyanates	Protect against cancer, heart disease and stroke	Broccoli
β-Carotene	Antioxidant	Carrot
Allium (allyl sulphides)	Protect against certain cancers and heart disease, boost the immune system	Garlic, onion
β-Carotene	Antioxidant	Sweet potato

(continued)

Table 1.2 (continued)

Nutraceuticals/ bioactive compounds	Putative biological effect	Vegetables
Lycopene, flavonoids	Protect against cancer, fight infection	Tomato
Momordicin and charantin	Anti-diabetic, blood purifier, hypertension, dysentery, anathematic	Bitter gourd
Isothiocyanates	Jaundice, liver infection, piles	Cauliflower/radish
Capsaicin, oleoresin	Anti-diarrhoeal, anti-rheumatic	Chilli
Chlorogenic acid	Anti-carcinogenic, anti-obesity and anti-diabetic properties	Brinjal

Source: Kalia and Singh (2018)

expected to reach to the level of USD 336 billion in 2023 and USD 722.49 billion in 2027 at a CGAR of 8.3% over the forecast period (https://www.prnewswire.com/). Similarly, in India, the status of nutra industry in 2019 stood around USD 5 billion but is expected to rise @ 21% CAGR to USD 11 billion in 2023 with a market share of 3.5% and USD 25 in the next decade. It covers the business segments of functional food, beverages and dietary supplements. The factors associated with rapid emergence of nutraceuticals are the following:

1. Consumers dissatisfied with drug costs and conventional healthcare are turning to unproven and untested natural product for treatment and prevention of diseases.
2. Chronic diseases with poor therapeutic alternatives.
3. Desire for personalized medicines.
4. Positive campaign in electronic and print media for nutraceutical.
5. Acceptance of nutraceutical products in large section of educated health-conscious population.
6. Scientific evidences in favour of nutraceuticals without major negative side effects.
7. New focus on preventing medicine.
8. Public perception that ‘natural is good’.

1.4.2 Nutraceuticals/Bioactive Compounds and Their Functions

The nutraceuticals or phytonutrients can be classified into various groups on the basis of alike protective functions as well as individual physical and chemical characteristics of the molecules. Focusing on nutraceuticals has greater potential for opportunities that are new, novel as well as exciting. The following is a list of important phytonutrients and their useful medicinal values. Natural antioxidants are substances in our foods, which prevent or slow the oxidative damage to our body by acting as ‘free radical scavengers’. Different kinds of food-grade nutraceuticals are shown in Fig. 1.2. Vegetables are rich sources of natural antioxidants such as

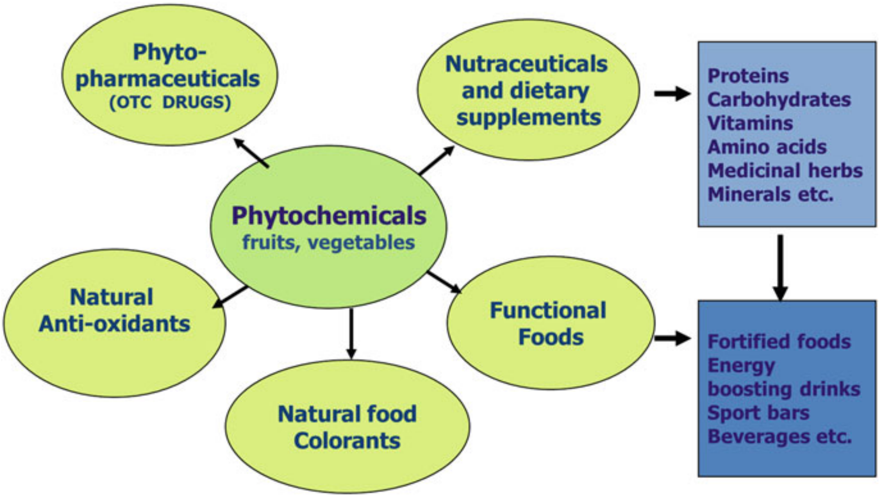


Fig. 1.2 Food-grade nutraceuticals

carotenoids, vitamin C, vitamin E, flavonoids, organosulphurs, glucosinolates and minerals like selenium, zinc and copper. The role of different phytochemicals in human and plant health is described in Table 1.3.

Glucosinolates: These are present in the vegetables of Brassica family and help in the detoxification enzymes in liver, white blood cells and cytokines, thereby helping in boosting immunity. The isothiocyanates, dithiolthiones and sulphoraphane are the bio-transformation products of glucosinolates that are involved in blocking enzymes, which are responsible for tumour growth in liver, lung, breast and gastrointestinal tracts (oesophagus, stomach and colon).

Flavonoids: Flavonoids constitute a subclass of phenols that improve the effects of ascorbate-vitamin C. These are beneficial in allergic conditions, inflammation, liver disorders, platelet aggregation, pathogens (bacteria and viruses), cancer and ulcers and act as antioxidants. These inhibit a number of specific enzymes, preventing, thereby, various diseases and maintaining a healthy body. Flavonoids block the angiotensin-converting enzyme (ACE) that is responsible for raising blood pressure. Different types of flavonoids in plants are given in Table 1.4, and classification of vegetables for flavonoid content is given in Table 1.5.

Indoles: Indoles include phytonutrients that interact with vitamin C, and their complexes bind with chemical carcinogens. These also help in activating the detoxification enzymes. The acid in stomach helps in the formation of bio-transformation products of indoles like the ascorbigen.

Isoflavones: This is a subclass of phenols found in beans and other legumes, and its function is similar to flavonoids in effectively blocking enzymes promoting tumour growth. The important enzymes include genistein and daidzein. The incidence of breast, uterine and prostate cancers is rare in people who consume legumes.

Table 1.3 Phytochemicals and health benefits

Phytochemicals	Role in plant system	Role in human health (when consumed in adequate quantity)
Phenolics	Signalling molecules, pigments, flavour, defence	Antioxidative, anti-inflammatory, antimutagenic, anti-carcinogenic, reduce cardiovascular diseases
Alkaloid	Plant defence	Antioxidant effects and health stimulants
Carotenoids	Pigmentation (yellow, orange, red), attract pollinators	Anticancer, anti-cardiovascular and age-related eye diseases, β-carotene: antioxidant, eye health; lycopene: antioxidant, prostate cancer
Anthocyanin	Pigmentation (purple, red)	Antioxidant, anti-inflammatory and anti-carcinogenic activity, cardiovascular disease prevention, obesity control, and diabetes alleviation properties
Steroids	Precursor for compounds	Anti-diabetic
Glucosinolates	Plant defence	Anticancer compounds
Omega-6-fatty acids (linoleic acid)	Plant defence and metabolic activities	Balanced ratio of omega-3-fatty acids (e.g. from fish) and omega-6-fatty acids (e.g. from vegetables) is essential for good health
Vitamins	Plant growth and development, quality	Antioxidants, anti-atherogenic, anti-carcinogenic, immunomodulator, prevent colon and breast cancers, some cardiovascular diseases, cataract, arthritis, certain neurological disorders
Organic acids	Precursor for compounds	Taste factor, human metabolism

Source: Kalia and Singh (2018)

Table 1.4 Flavonoids and their vegetable sources

Flavonoid	Source
Quercetin	Tomato, potato, broad beans, broccoli, Italian squash, kale and onion
Kaempferol	Radish, horseradish, endive and kale l
Flavanols	Legumes
Luteolin	Beetroot, Brussels sprout, cabbage, cauliflower
Anthocyanidins	Red potato

Phenols: Phenolic compounds comprise one of the most numerous and widely distributed groups of substances in the plant kingdom, with more than 8000 phenolic structures currently known. Natural phenolics can range from simple molecules, such as phenolic acids, to highly polymerized compounds, such as tannins, and their occurrence in foods is extremely variable. The term phenolic or polyphenol is chemically defined as a substance that possesses an aromatic ring, bearing one or more hydroxy substituents, including its functional derivatives (esters, methyl esters, glycosides, etc.). The three groups of phenolic compounds which commonly occur in food materials are (1) simple phenols and phenolic

Table 1.5 Flavonoid content range in different vegetables

Flavonoid range	Sources
<5–10 mg/100 g	Garlic, beans, carrot, cucumber, tomato, radish, potato
5–10 mg/100 g	Spinach, Brussels sprout, cabbage, lettuce, kale, turnip greens, cauliflower, sweet pepper
10–50 mg/100 g	Broccoli, celery, knol khol, onion
>50 mg/100 g	Broad beans, parsley, sweet potato leaves, chilli

Source: Published literature online and Kalia and Singh (2018)

acids, (2) hydroxycinnamic acid derivatives and (3) flavonoids. The phenolics content in different vegetables is given in Table 1.6.

The most common group of plant phenolics are the flavonoids, the structures of which are based on that of flavone, consisting of two benzene rings linked through a three-carbon γ-pyrone ring. Common classes of flavonoids include flavones, flavonols, isoflavones, anthocyanins, catechins (flavanols) and flavanones. More than 4000 flavonoids have been reported and, except for catechins, most flavonoids occur in nature as glycosides:

1. Flavonols: quercetin kaempferol, myricetin, isorhamnetin
2. Flavones: apigenin, luteolin
3. Flavanones: hesperetin, naringenin, eriodictyol
4. Isoflavones: genistein, daidzein
5. Flavan-3-ols: catechins, epicatechins, theaflavins, thearubigins
6. Anthocyanidins: cyanidin, delphinidin, malvidin, pelargonidin

Thiols: Thiols comprise sulphur-containing phytonutrients present in garlic and cruciferous vegetables (cabbage, turnips and other members of the mustard family). Allylic sulphide subclass is abundantly found in garlic, onions, leeks, shallots and chives and is released when the plants are cut or smashed. These possess antimutagenic and anti-carcinogenic properties as well as immune-enhancing and cardiovascular protective properties. Garlic and onions activate liver detoxification enzyme systems and are also effective against tumours, bacteria, fungi, viruses, parasites, cholesterol and platelet/leukocyte adhesion factors.

Anthocyanins: Anthocyanins are natural pigments belonging to the flavonoid family. They are responsible for the blue, purple, red and orange colour of many vegetables. Anthocyanins are capable of acting on different cells involved in the development of atherosclerosis, one of the leading causes of cardiovascular dysfunction. On the one hand, they can interfere with glucose absorption, and on the other hand they may have a protective effect on pancreatic cells.

Table 1.6 Different phenolics content in common vegetable crops

Phenolics	Brinjal	Cabbage	Cauliflower	Carrot	Bitter gourd
Total polyphenols (mg/100 g)	2.64–16.10	0.55–15.85	1.75–34.18	1.45–12.30	0.50–7.50
Chlorogenic acid	0.01–2.69	–	–	0.02–1.35	–
Caffeic acid	0.00–0.77	0.00–0.01	–	–	–
Sinapinic acid	–	0.00–0.08	–	–	–
Resveratrol	–	0.02–0.31	0.04–1.21	–	–
Gallic acid	0.00–0.12	BDL	–	–	–
Cinnamic acid	–	0.01–0.86	0.02–0.76	–	–
Quercetin	–	0.00–0.04	–	–	–
Protocatechuic acid	0.00–0.33	0.00–0.61	0.11–1.25	–	0.00–0.11
Vanillic acid	0.00–6.17	0.00–0.06	0.01–1.74	0.00–0.09	–
Syringic acid		0.16–0.84	0.00–0.48		0.19–8.97
Ferulic acid	0.00–0.45	0.16–11.35		0.00–0.58	–
P-coumaric acid	0.00–0.24	0.00–0.04	0.00–0.02	0.00–1.57	–

Source: IFCT (2017), Kalia and Singh (2018)
– Not detected

Microencapsulation of anthocyanin pigments of black carrot by spray drier has led to acylated and non-acylated anthocyanins. They are temperature resistant and water soluble with strong colours, have been used to colour food and are stable at pH <4. The carrot extract is being used to colour drinks, pastries and other beverages.

Betalains: Betalains have been widely used as natural colourants for many centuries, but their attractiveness for use as colourants of foods (or drugs and cosmetics) has increased recently due to their reportedly high antioxidative, free radical scavenging activities and concerns about the use of various synthetic alternatives. All betalains are water soluble, which limits the use to fresh foods, foods packed under modified atmosphere or foods that undergo no heat treatment. It is mainly used in frozen products (ice cream, yoghurt). Dry betanin is more stable, and it is used as colour in instant foods and powdered soft drinks. It is also stable in high sugar conditions and can thus be used in candies and fruit gels and fillings.

Carotenoids: The carotenoid family consists of carotenes and xanthophylls. There are more than 600 naturally occurring carotenoids. The subclass terpenes comprise bright red, orange and yellow pigments present in various vegetables, viz. tomatoes, spinach, oranges, pink grapefruit and red palm oil. Carotenoids play an important role in plant reproduction, through their role in attracting pollinators and in seed dispersal, and are essential components of human diet. Carotenoids provide protection to vision and eye function, and against macular degeneration and cataracts. Carotenoids are credited with biological promotion of immune system response. Carotenoids are associated with inhibition of several types of cancers including cervical, oesophageal, pancreatic, lung, prostate, colorectal and

Table 1.7 Major carotenoids, their vegetable sources and functions

Carotenoid	Sources	Functions
Lycopene	Tomato, watermelon	Reduces the risk of colon and bladder cancer, prostate cancer (Giovannucci et al. 2002), cardiovascular disease (Kohlmeier and Hastings 1995)
Beta-carotene	Carrot, cole crops, sweet potato, tomato, bell pepper	Improves immune response to contagious diseases. Inhibits early stages of tumour development; decreases lung, skin and digestive tract cancers. Can suppress AIDS and Alzheimer's disease. Protects against asthma and heart diseases.
Alpha carotene	Carrot, Pumpkin	Lowers the risk of lung cancer (Omenn et al. 1996)
Lutein	Cole crops, spinach, turnip leaves	Improves immune response, protects the macula of the eye from age-related deterioration. Lowering of the risk for cataract (Moeller 2000)
Zeaxanthin	Cole crops, turnip leaves, peas, beans	Protects the macula of the eye from age-related deterioration

stomach. Unlike carotene, lycopene is not converted into vitamin A, but it is a powerful antioxidant and an efficient scavenger of oxygen, thus having anticancerous effect. It is a potent antioxidant in vitro and associated with decreased risk of certain cancer in epidemiological studies. The different types of carotenoids, their sources and functions in human health are given in Table 1.7.

Chlorophylls: Chlorophyll is the most important plant pigment and a 'real life force' that nature uses to explode plants into greenery. The antimutagenic properties of chlorophylls have been demonstrated in various assays, and clearly, intake of chlorophyll has the potential to act as a chemopreventive compound in humans.

Yang et al. (2001) reviewed the inhibition of carcinogenesis by dietary polyphenolic compounds and questioned the link between the antioxidative and anticarcinogenic properties, asserting that polyphenols may inhibit carcinogenesis by affecting the molecular events in the initiation, promotion and progression stages of cancer. Beyond their antioxidative properties, flavonoids may act in a variety of ways, such as deactivating carcinogens, inhibiting the expression of mutated genes and the activity of enzymes that promote carcinogenesis, and promoting detoxification of xenobiotics (Kris-Etherton et al. 2002).

The health-related properties of phenolic compounds, particularly flavonoids, are believed to be based on their antioxidant activity as hydrogen-donating free radical scavengers (Rice-Evans et al. 1996; Prior and Cao 2000). The primary target of radicals is proteins (including enzymes), lipids (relevant to the induction of heart disease), DNA (relevant to the induction of cancer) and RNA. However, the oxidative event that occurs most frequently inside the body is the oxidation of the unsaturated fatty acid components of cell membranes forming lipid peroxides.

Many researchers have shown that lipid peroxides and reactive oxygen species are involved in the development of a variety of diseases, including cancer, atherosclerosis, heart disease, kidney damage and even accelerated ageing. Flavonoids are also metal chelators and have been found to bind metals, such as copper and iron, which catalyse lipid oxidation. Although flavonoids are widely distributed in plant foods, the isoflavones are found in just a few botanical families. Although present in several legumes, soybean is the principal dietary source. The isoflavones genistein and daidzein and their β-glucosides are present at up to 3 mg/g of soybean.

1.4.2.1 Phyto-Oestrogens and Phytosterols

Isoflavones, lignans and stilbenes are phyto-oestrogens, a group of non-steroid plant constituents that elicit oestrogen-like biological response (Murphy and Hendrich 2002). Lignans are diphenols associated as minor components with dietary fibre. Once ingested, plant lignans are converted by bacteria in the large intestine into enterolactone and enterodiol, which are called mammalian lignans because they have been found only in mammals (Crosby 2005). Mammalian lignans are associated with a reduced risk of CVD and cancer. Phyto-oestrogens can compete with steroid hormones for various enzymes and receptors and stimulate the production of sex hormone-binding globulin in the liver. Thus, they may alter steroid hormone metabolism and may inhibit growth and proliferation of hormone-dependent cancer. Like other phenolic compounds, phyto-oestrogens have antioxidant activity, and like oestrogens, they can influence lipoprotein metabolism and enhance vascular reactivity. Phyto-oestrogens, therefore, have potential protective effects against CVD.

Plant sterols or phytosterols are structurally similar and functionally analogous to the animal sterol, cholesterol. Phytosterols are triterpenoids occurring in both free and esterified forms. Of more than 40 phytosterols identified, β-sitosterol, stigmasterol and campesterol are the most abundant and are predominantly supplied by vegetable oils (Hicks and Moreau 2001), which are rich sources of sterol esters. A less abundant class of related compounds are the plant stanols or phytostanols, which are completely saturated forms of phytosterols. Phytostanols are derived primarily from corn. Phytosterols and phytostanols inhibit intestinal absorption of cholesterol.

1.4.2.2 Tocotrienols

Tocotrienols are unsaturated analogues of tocopherol (vitamin E). A number of plant foods, ranging from kale and broccoli to cereal grains and nuts, have also been found to contain tocotrienols. There are at least four known forms of tocotrienol, with γ-tocotrienol as the main and most potent cholesterol-lowering form. The cholesterol-lowering effect of tocotrienols is attributed to their ability to inhibit hydroxymethylglutaryl-CoA (HMG-CoA) reductase, the rate-limiting enzyme in the cholesterol synthesis pathway. It has been suggested that α-tocopherol attenuates the inhibitory effect of γ-tocotrienol. Tocotrienols have also been demonstrated to possess vitamin E activity, antioxidant activity and antitumor properties. It was hypothesized that the inhibition of HMG-CoA reductase by tocotrienols also results in suppression of tumour growth.

1.4.2.3 Organosulphur Compounds

Allium compounds are organosulphur compounds (OSCs) found in *Allium* vegetables such as garlic, onion, scallion, chive, shallot and leek, which account for the distinctive flavour and aroma as well as the many reported medicinal effects of these vegetables. The OSCs in *Allium* vegetables have been reported to exert various physiological effects, including antimicrobial activity, lipid-lowering effect, hypocholesterolaemic activity, antithrombic effect, inhibition of platelet aggregation, hypoglycaemic activity and lipoxygenase and tumour inhibition.

1.4.2.4 Glucosinolates

The glucosinolates are sulphur-containing glucosides prevalent in the cruciferous family of vegetables, especially the Brassica (e.g. cabbage, broccoli, Brussels sprouts, cauliflower), and are also present at relatively high levels in oilseeds such as rapeseed and in condiments such as mustard seed. Over a 100 different glucosinolates have been identified in the plant kingdom, but only about 10 are present in cruciferous vegetables. Although glucosinolates are structurally diverse, there are only three principal groups, based on the side-chain structure: aliphatic, aromatic and indolyl (heteroaromatic) glucosinolates. When the plant tissue is damaged by food preparation or chewing, the glucosinolates are brought into contact with and are hydrolysed by the endogenous enzyme, myrosinase, to yield a complex mixture of products, mainly isothiocyanates, nitriles and thiocyanates. Glucosinolate breakdown products exert a variety of antinutritional and toxic effects in higher animals, the most thoroughly studied of which is the goitrogenic effect of some products. At present, there is little or no epidemiological evidence of this goitrogenic effect causing a disease in humans. On the other hand, from in vitro and in vivo studies, it was found that isothiocyanates affect many steps of cancer development, including modulation of phase I and II detoxifying enzymes, functioning as a direct or indirect antioxidant by phase II enzyme induction, modulation of cell signalling, induction of apoptosis (programmed cell death), control of the cell cycle and reduction of *Helicobacter* infections. Apoptosis and modulation of phase I and phase II detoxification pathways have been considered the most important mechanisms by which glucosinolate/isothiocyanates inhibit carcinogenesis. Phase V enzymes defend carcinogenic substances. Examples are glutathione *S*-transferase and NADPH-quinone oxidoreductase. These enzymes catalyse the conversion of mutagenic metabolites or their precursors into compounds that are less reactive or more readily excreted. Glucosinolates are not bioactive until they have been enzymatically hydrolysed to the associated isothiocyanates.

1.5 Nondigestible Carbohydrates: Dietary Fibre and Prebiotics

There are three main types of carbohydrates that are undigestible in the human small intestines: nonstarch polysaccharides (NSP), resistant starch (RS) and nondigestible oligosaccharides (NDOs) (Voragen 1998). Several definitions for dietary fibres have been suggested. The most widely accepted is a physiological definition, which considers dietary fibres as vegetable wall residues that are resistant to enzymatic hydrolysis in the small intestine. A chemical definition describes dietary fibres as nonstarch polysaccharides, although more recently some workers include resistant starch as a new class. The most commonly used definition is the following: dietary fibres are oligosaccharides, polysaccharides and their hydrophilic derivatives, which cannot be digested by the human digestive enzymes to absorbable components in the upper alimentary tract; this definition includes lignin (Thebaudin et al. 1997).

NDOs occur naturally in raw food materials and food products. The most prominent examples are fructans (e.g. inulin), which occur in edible parts of various plant foods like onion, artichoke, chicory, leek and garlic. Galactosyl sucroses (raffinose and stachyose) are found in soybeans and other leguminous seeds, while xylooligosaccharides occur in bamboo shoots. In some foods, NDOs are generated during processing. The NDOs have been described as prebiotics (Crittenden and Playne 1996). A prebiotic is a nondigestible food ingredient that positively affects the host by selectively stimulating the growth and/or activity of one or a limited number of beneficial bacterial species already resident in the colon (Gibson and Roberfroid 1995). For this reason, resistant starches, although considered as fibres, are not necessarily prebiotics.

Dietary fibres have several recognized physiological effects: modulation of glucose absorption, regulation of gastrointestinal transit time, faecal bulking, acidification of colonic content and control of cholesterol bioavailability. Prebiotics, on the other hand, selectively modify the colonic microbiota and modulate hepatic lipogenesis.

1.6 Vitamin C and Vitamin E

Vitamin C scavenges free radicals and reduces cancer of the digestive tract. It regenerates vitamin E from the tocopheroxyl radical and inhibits plaque formation in blood vessels by preventing oxidation of LDL cholesterol. Thus, it reduces the risk of arteriosclerosis. Vitamin C inhibits the formation of carcinogenic nitrosamines in the body and reduces cancer risk. There are reports convincing the fact that vitamin C can reduce the occurrence of cancer of oesophagus, stomach and larynx. Sources of vitamin C include chilli, bitter gourd, tomato, leafy vegetables, etc.

Vitamin E helps to protect the conjugated bonds of polyunsaturated fats and beta-carotene from being broken down. It prevents oxidation of LDL cholesterol. It lowers the risk of heart diseases and cancer. It is considered to be an anti-ageing agent. Leafy vegetables and cole crops are major sources.

1.6.1 Vegetables Rich in Nutraceuticals/Bioactive Compounds

The interest in nutraceuticals is not limited to the food industry. University departments including agriculture, medicine, pharmacy, human ecology, food science, animal science and botany are all currently involved in nutraceutical research. As nutraceuticals and edible colours are natural compounds, they are always regulated by several biochemical pathways and controlled by genetical and environmental factors. From early times, people have knowingly or unknowingly selected several vegetable crops for their food purpose. The biochemical pathway and synthesis of the compound are controlled by one or many genes, which are scattered in the available or unknown germplasm of a particular vegetable crop. Conventional breeding in conjunction with molecular biology has bright prospects of developing vegetable varieties high in nutraceuticals, edible colours and bioactive compounds suitable for fresh market as well as fusion food industry. Increasing the health functionality of vegetable crops through breeding and/or genetic modification should create products that deliver greater health benefits than current varieties. Nevertheless, research efforts strive to improve our understanding of crop manipulations for nutrition, and in many cases, substantial progress has been made by using conventional and molecular tools.

Tomato: Tomato has received significant attention because of interest in lycopene, the primary carotenoid found in this fruit, and its role in cancer risk reduction. Tomato and tomato-based sauces, juice and ketchup account for more than 85% of the dietary intake of lycopene. The lycopene content of tomato depends on species and increases as the fruits ripen. Processing of tomato increases the concentration of bioavailable lycopene. Lycopene in tomato paste is four times more bioavailable than in fresh tomatoes. This is because lycopene is insoluble in water and is tightly linked to vegetable fibre. Thus, processed tomato products such as pasteurized tomato juice, soup and sauce contain the highest concentration of bioavailable lycopene. Recently, a ‘purple’ tomato, highly enriched with anthocyanins, was produced by the ectopic expression of two selected transcription factors from the ornamental flower snapdragon. In addition to being enriched with anthocyanin, these fruits also prolonged the life of cancer-susceptible mice, suggesting that they have additional health-promoting effects.

Brinjal: The multiple health benefits of brinjal which include antioxidant, anti-diabetic, hypotensive, cardioprotective and hepatoprotective effects are largely attributed to its phenolic content (chlorogenic acid). In addition, the content of chlorogenic acid (CGA) in brinjal increases after the thermal treatments normally used for cooking. In fact, eggplant ranks among the vegetables with highest oxygen radical absorbance capacity due to its high content in phenolics.

Red chilli: Pungency and colour are the two main quality attributes in chilli. The red colour of chilli is due to the presence of the carotenoid pigment like capsanthin (major, 35%), zeaxanthin, violaxanthin, cryptoxanthin and beta-carotene. These pigments are present in chilli in esterified form and to a small extent in non-esterified form. Chilli oleoresin is used in many Indian foods like sauces and meat products to impart desired taint and pungency. The hot flavour of chilli has been attributed to the presence of a group of closely related compounds called capsaicinoides. Capsaicin and dihydrocapsaicin are the two main active components that occur for approximately 90% of the pungency. Capsaicin is currently used in tropical ointments in concentration between 0.025% and 0.075% to relieve minor aches, muscle pain and joint pains. Capsaicin is also being explored as a possible cure for diabetes, prostate cancer and pesticide to deter pest.

Beetroot: The red colour of beet is derived from anthocyanin and water-soluble betalain pigments called betacyanin and betaxanthin. These pigments are of red-purple and yellow colour, respectively. Beetroot powder is a very popular colouring agent for use in soaps and cosmetic products. Some of the other active constituents include saponiside, phytosterol, leucine, etc. Beetroot is believed to boost the body's natural defences in the liver and regenerate immune cells. It contains soluble fibre, which can reduce high blood cholesterol levels. Its phytochemicals, carotenoids and flavonoids act as cardiotonic and prevent LDL (bad cholesterol) from being oxidized and deposited in the arteries. It is a wonderful cleansing and nourishing tonic that normalizes the body's pH balance (reducing acidity) and purifies the blood by flushing away fatty deposits and improving circulation.

Further, the edible colours are natural pigments found in tissue of plants such as anthocyanins, betalains, carotenoids and chlorophylls. These pigments have nutraceutical properties and have been implicated in regimes to maintain human health, protect against chronic disease(s) or restore wellness by repairing tissues after disease has been established. The major colours and their source are given in Table 1.8.

Carrot: Vegetable carrot is available in red, yellow, purple or even black colour. The variety of pigments contained in them perform a range of protective functions in the human body. Many of the pigments serve to shield plant cell during photosynthesis. Red carrots derive their colour from lycopene, a type of carotene believed to guard against heart disease and cancer. Yellow carrot accumulates xanthophylls, pigments similar to beta-carotene that support good eye health. Purple carrots possess an entirely different class of pigments, anthocyanin, which act as an antioxidant. There is enormous diversity in the pigmentation of European and Asiatic carrot. The Asiatic types are mostly yellow and purple. The Asiatic type collections such as Local Rewari Black and Local Jaipur Black have higher anthocyanin content. Few molecular markers linked to major genes or QTL have been developed. Examples have been reported for carotene QTLs and the Y_2 gene and the *Rs* sugar-type gene. To date, seven monogenic traits have been mapped for carrot: *yel*, *cola*, *Rs*, *Mj-1*, *Y*, Y_2 and P_1. QTLs have been mapped for total carotenoids and five component carotenoids, namely phytoene, α-carotene, β-carotene, zeta-carotene and lycopene, and the majority of the structural genes of the carotenoid pathway are now placed into this map. Anthocyanin accumulation in the carrot phloem is conditioned by the P_1 locus, with purple (P_1) dominant to non-purple (p_1). The nutrient value of common varieties is given in Table 1.9, and variety images are shown in Fig. 1.3. A process of chain from production to processing of black carrot is shown in Fig. 1.4.

Table 1.8 Vegetable sources as food colours

Colour	Pigments	Vegetables
Red	Lycopene	Tomatoes (Pusa Rohini), watermelon, *Momordica* seed aril powder, pumpkin, muskmelon, flowers of pumpkin, red carrot (Pusa Rudhira, Pusa Vrishti, Pusa Vasuda), paprika (KLPL-19), radish (Pusa Gulabi)
Orange	Beta-carotene	Carrots (Pusa Nayanjyoti, Pusa Yamdagini, Nantes), cantaloupe, pumpkin, sweet potatoes
Blue/ purple	Anthocyanins	Red amaranth (Pusa Lal Chaulai), Indian spinach fruit, eggplant fruit skin, radish (Pusa Jamuni), purple broccoli (Palam Vichitra), red cabbage (Kinner Red)
Yellow	Lutein	Yellow corn, pale carrot (Pusa Kulfi)
Green	Chlorophyll	Spinach, beet leaf, green amaranth, broccoli (Pusa KTS-1, Palam Samridhi), kale, vegetable mustard (Sag Sag-1), asparagus, drumstick leaves
Black	Anthocyanins	Black carrot (Pusa Asita), beetroot (Detroit Dark Red, Crimson Globe)
White	Anthoxanthin	Cassava (white flesh varieties), white cauliflower

Table 1.9 Carotenoids and anthocyanin content in tropical carrot varieties

Carotenoids	Pusa Kulfi	Pusa Meghali	Pusa Rudhira	Pusa Kesar	Pusa Vrishti	Pusa Asita
Total carotenoids (mg/100 g)	377	4630	5148	5065	2539	436
Lutein (mg/100 g)	35	35	110	94	102	191
Lycopene (mg/100 g)	BDL	33	1386	914	1335	29
β-Carotene (mg/100 g)	BDL	3982	831	784	749	26
Anthocyanin (mg/100 g)						339

Source: Kalia and Singh (2018)

Radish: Radish is an important root crop having anthocyanin-rich Pusa Jamuni variety and lycopene-rich Pusa Mridula, Chinese Pink, Palam Hriday and Pusa Gulabi, which provide new avenues to consumers' health and nutraceutical industry. Pusa Jamuni roots are bulky and contain a fair amount of anthocyanin (8.04 mg/100 g) (Table 1.10).

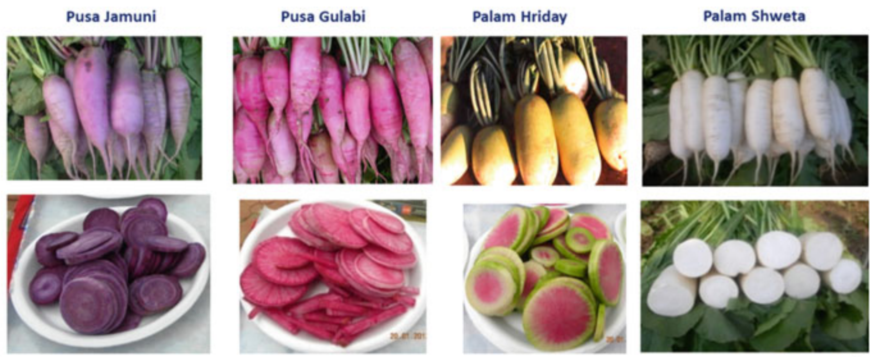
***Brassica* vegetables**: Orange-, purple- and green-coloured genotypes/varieties/ hybrids of cauliflower are now available for cultivation. These are naturally evolved colours through natural mutation and human selection. Their evolution pattern and common local types are shown in Fig. 1.5. This also shows the coloured Romanesco and Sicilian purple types, which are evolved as intermediates of calabrese and cauliflower.

A spontaneous '*Or*' mutant gene in cauliflower showed that the predominant carotenoid that accumulated in the affected tissues is β-carotene, which can reach levels several 100-fold higher than those found in the comparable tissues of wild-

Fig. 1.3 Tropical carrot varieties with diverse colours

Fig. 1.4 A cooperative (UNATI) in Punjab has taken up production of anthocyanin-rich black carrot Pusa Asita for juice

Table 1.10 Nutrient-rich coloured radish varieties



Variety	Ascorbic acid (mg/100 g)	Anthocyanin (mg/100 g)	Total carotenoids (mg/ 100g)
Pusa Gulabi	39.25	4.41	15.6
Pusa Jamuni	44.82	8.04	2.5
Palam Hriday	56.94	2.00	2.01

type cauliflower (Li et al. 2001). The '*Or*' gene, which encodes a DnaJ cysteine-rich domain-containing protein, confers orange curd with high levels of β-carotene accumulation. Rather than directly regulating carotenoid biosynthesis, the '*Or*' gene appears to mediate the differentiation of plastids and/or non-coloured plastids in apical shoot and inflorescence meristematic tissues of

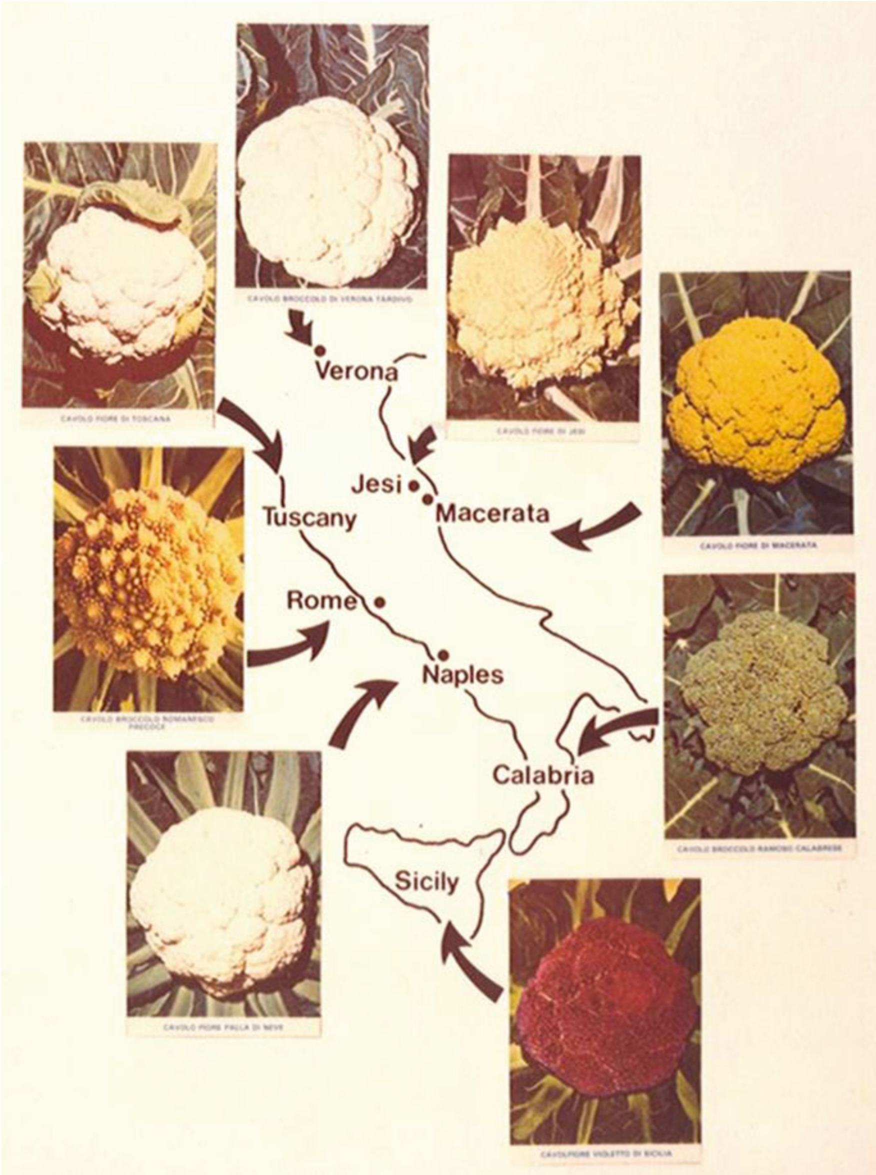


Fig. 1.5 Colour diversity in broccoli and cauliflower. (Source: Crisp, Person. communication)

curd into chromoplasts for the associated carotenoid accumulation (Li et al. 2001). Transformation of the '*Or*' gene into wild-type cauliflower converts the white colour of curd tissue into distinct orange colour with increased level of β-carotene. Examination of the cytological effects of the '*Or*' transgene revealed that expression of '*Or*' transgene leads to the formation of large membranous chromoplasts in the cauliflower curd cells of the '*Or*' transformants (Lu et al. 2006). Singh et al. (2020) performed introgression of *Pr* gene from Sicilian Purple in Indian cauliflower through backcross breeding. They reported it as under genetic control of incomplete dominance. Similarly, observations were also made by Chiu et al. (2010) in Graffiti, a purple cauliflower of snowball group.

Orange cauliflower: The source gene '*Or*' is a spontaneously occurring mutant, which was originally found in white-curded autumn crop cv. Extra Early snowball. This trait is absent in Indian cauliflower, where a large population is suffering from vitamin A deficiency. Hence, we at IARI designed and led the biofortification of Indian cauliflower with beta-carotene-enhancing native '*Or*' gene following marker-assisted breeding. Molecular tools were also simultaneously developed for rapid introgression of the gene. The eye-appealing orange cauliflower was first discovered in Bradford Marsh, Ontario, Canada, in 1970. The orange cauliflower results from a spontaneous mutation of a single dominant gene designated as '*Or*' for orange gene (Crisp et al. 1975). Ripley and Roslinsky (2005) identified an ISSR marker for 2-propenyl glucosinolate content in *Brassica*.

Orange Chinese cabbage: The *Or* mutation in Chinese cabbage is a recessive, single-locus mutation that causes the head leaves of the plant to accumulate carotenoids and turn orange. Sequence-characterized amplified region (SCAR) markers linked to the *Or* gene were identified based on random amplified polymorphic DNA (RAPD) and amplified fragment length polymorphism (AFLP) by performing a bulked segregant analysis (BSA) using a doubled haploid (DH) population derived from the F_1 cross between 91 and 112 (white-head leaves) and T12 and 19 (orange-head leaves) via microspore culture. Zhang et al. (2008) found SCAR markers linked to '*Or*' gene inducing beta-carotene accumulation in Chinese cabbage.

Broccoli: It is high in vitamin C and soluble fibre and contains multiple nutrients with potent anticancerous properties including di-indolylmethane and selenium. The 3,3′-di-indolylmethane found in broccoli is a potent modulator of the innate immune response system with antiviral, antibacterial and anticancer activities. It also contains the compound glucoraphanin, which can be processed into anticancerous compound sulphoraphane. Intake of broccoli has been found to reduce the risk of prostate cancer. Broccoli seeds particularly rich in glucoraphanin (20–50 mg/g) have proved to be ideal for the isolation of glucoraphanin on the preparative scale. Different coloured varieties available in broccoli are shown in Fig. 1.6, and their nutrient composition is given in Table 1.11.

Cucumber: The common cucumbers (*Cucumis sativus* L.) always develop white fruit with lower carotenoid, 22–48 μg/100 g fresh weight. Xishuangbanna gourd (*Cucumis sativus* var. *xishuangbannanesis*) develops orange fruit rich in carotenoid, ~700 μg/100 g flesh weight, which makes this germplasm attractive to plant improvement programmes interested in improving the nutrition of cucumber. A study undertaken to identify quantitative trait loci (QTL) associated with orange

Fig. 1.6 Broccoli varieties with diverse colours

Table 1.11 Nutrient profile of indigenous broccoli varieties

Nutrients	Green sprouting type		Coloured heading type	
	Palam Samridhi	Palam Haritika	Palam Kanchan	Palam Vichitra
Protein (%)	3.62	3.86	3.16	3.85
Carbohydrates (%)	5.60	5.40	5.50	5.50
Total chlorophyll (mg/g)	0.42	0.39	0.22	0.13
Total carotenoids (mg/g)	1.35	0.88	1.40	0.36
Ascorbic acid (mg/100 g)	81.31	75.54	67.45	58.80
Calcium (mg/100 g)	54.00	54.18	61.93	79.88
Phosphorus (mg/100 g)	61.05	62.00	52.00	79.00
Iron (mg/100 g)	0.90	0.91	1.40	1.61
Sodium (mg/100 g)	26.00	23.10	23.00	25.00
Potassium (mg/100 g)	123.82	124.00	324.66	314.00

fruit flesh showed two genetic linkage maps with the markers of RAPD, SCAR, SSR, EST, SNP, AFLP and SSAP, which defined a common collinear region containing four molecular markers (3 dominant and 1 codominant) on linkage group (LG) LG6 in Map 1 and LG3 in Map 2. These regions contained QTL associated with orange mesocarp (mc)/endocarp (ec) colour [mc6.1/ec6.1 (Map1) and mc3.1/ec3.1 (Map2)]. Biochemical analyses indicated that β-carotene (β) and xanthophyll (x) were the two predominant carotenoids in mc and ec tissues. QTLs controlling the content of β-carotene in endocarp (edb3.1) and xanthophyll in mesocarp (mdx3.1) mapped to the same interval as mc3.1 and ec3.1, respectively, in Map2. Moreover, one cucumber carotenoid biosynthesis gene, NCED (9-*cis*-epoxycarotenoid dioxygenase), mapped to the same interval as orange flesh colour QTLs (mc6.1/ec6.1 and mc3.1/ec3.1) in both maps. The QTLs identified herein should be considered for use in marker-assisted selection for introgression of β-carotene genes into commercial cucumber.

1.6.2 Vegetable Breeding for Quality Traits and Nutraceuticals

The common breeding methods for biofortification are selection, recurrent breeding, backcrossing and hybrid breeding. However, the new methods employing molecular tools become more popular to fasten the speed for introgression of these novel traits into commercial varieties/hybrids. A summary of methods is presented in Fig. 1.7.

1.6.2.1 Requirements for Development of Biofortified Varieties

The breeding of biofortified varieties needs the following considerations:

- Source germplasm must have high density of target nutrient(s).
- Biofortified varieties must have wider adaptability with high content of target nutrients.
- Processed forms of variety/hybrid must retain sufficient quality attribute, i.e. nutrients and antioxidants.
- Bioavailability of nutrients in human body must be high.
- Acceptance of biofortified crops by target groups, i.e. farmers and consumers.

1.6.2.2 Approaches in Breeding for Quality Attributes in Vegetables

- Evaluation of germplasm and identification of potential donors
- Pre-breeding and product enhancement to develop germplasm combining one or more micronutrients
- Search for promoters for increased bioavailability and reduced antinutrients in biofortified varieties
- Transgressive segregation or heterosis for quality traits
- Molecular breeding for handling complex quality traits
- Transgenic approach for genes from alien sources

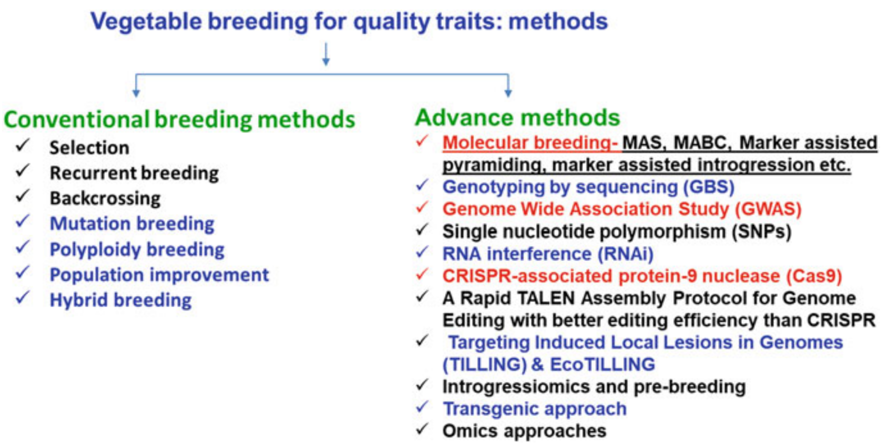


Fig. 1.7 Vegetable breeding methods for quality traits

- Exploring gene editing approaches for biofortification—CRISPR/Cas9, TALENS, etc.
- Use of innovative diagnostic tools for handling micronutrient traits

1.7 Phytochemical-Rich Varieties

Vegetable varieties were developed across the vegetable crops which are rich in coloured compounds such as lycopene, anthocyanin, beta-carotene and chlorophyll (Table 1.12). These pigment compounds have been identified to have a positive role in human health. Varieties developed in different vegetable crops can be used as a natural source for extraction of dyes, edible food colour and also functional food development.

1.7.1 Pre-breeding for Nutrient-Rich Genetic Stocks

Solanum pimpinellifolium is a good wild *source for increasing* acidity in cultivated varieties. *Solanum pennellii* allele increased glucose and fructose contents in cultivated tomato fruits in various genetic backgrounds and environments (Fridman et al. 2000). They reported that the differences between the *Brix9-2-5* alleles (on chromosome 9) are associated with a polymorphic intronic element that modulates sink strength of tomato fruits. The orange- and orange-red-fruited plants from *S. esculentum* × *S. hirsutum* contain high beta-carotene. The beta-carotene content was improved by interspecific hybridization between *S. esculentum* and *S. hirsutum* f. *glabratum*. This species has been a source for genes to develop Caro Red (Rutgers × *S. hirsutum*), which has ten times more beta-carotene than the standard variety. Green fruit colour from *Abelmoschus manihot* to *A. esculentus* 'Sel-2' is suitable for freezing. The jointless *j2* allele was introgressed from *S. cheesmanii* in *S. esculentum*. In combination with *sp*, *j2* has been bred into many processing varieties, allowing a large-scale mechanical harvest of tomato fruits (Quinet et al. 2019).

In French bean, a wild species *Phaseolus phyllanthus* had high sulphur-containing amino acids, which may be involved in hybridization programme to improve protein content and quality (Baldi and Salamini 1973). In *Brassica* vegetables, *Brassica villosa* has been used to increase glucosinolates in broccoli (Sarikamis et al. 2006). In chilli, landraces derived from natural inter-specific crosses between *C. chinense* and *C. frutescens* (Bosland and Baral 2007) have highly pungent fruits and are potential sources of capsaicinoids with broad-spectrum ethno-pharmaceutical.

Table 1.12 Vegetable varieties rich in phytochemicals

Crop	Variety	Major phytochemicals
Carrot	Pusa Rudhira	Lycopene
	Pusa Meghali, Pusa Yamdagini, Pusa Nayanjyoti	β-Carotene
	Pusa Asita	Anthocyanin
	Pyusa Kulfi	Lutein
Chenopodium	Pusa Bathua-1	Vit A, Vit C, Fe and Ca
Palak	Pusa Jyoti, Pusa Bharti	Vit A, Vit C, Fe, Ca
Tomato	Pusa Uphar, Pusa Hybrid-2, Pusa Rohini	Vit C, lycopene
Vegetable mustard	Pusa Sag-1	Vit C, carotene
Amaranths	Pusa Kiran, Pusa Kirti	Vit A, Vit C, Ca, Fe
	Pusa Lal Chaulai	Betalains
Bitter gourd	Pusa Hybrid-1, 2 Pusa Rasdar	Vit A, Vit C, Fe, Ca
Broad bean	Pusa Sumit	Protein
French bean	Pusa Parvati	Protein
Pumpkin	Pusa Hybrid-1, Pusa Vikas	Vit A
Radish	Pusa Mridula	Lycopene, Ca, Fe, Mg
	Pusa Jamuni	Anthocyanin, Vit C
	Pusa Gulabi	Anthocyanin, Vit C
Paprika	KTPL-19	Capsanthin
Beet root	Detroit Dark Red	Betalain, Vit B and C; beta-carotene, folic acid
Cabbage	Red Cabbage	Anthocyanin, Vit C, glucosinolates
Broccoli	Palam Vichitra	Anthocyanin, Vit C, glucosinolates

1.7.2 Biofortification of Broccoli for Health Beneficial Glucosinolates

Broccoli is found to have the healthiest glucosinolate profiles since it contains glucoiberin and glucoraphanin. Faulkner et al. (1998) reported that the content of these was reported to be 0.1–1.0 μmol/g dw and 0.8–11.1 μmol/g dw, respectively. Many wild relatives of *Brassica oleracea* have high content of these glucosinolates. *Brassica villosa* was found to be the potential donor for higher content of glucoiberin and also glucoraphanin. It contains both glucosinolates as 119 and 1.4 μmol/g dw, respectively. In F_1, their content was reported to be 26.4 and 81.8 μmol/g dw, respectively. It had no progoitrin and gluconapin (3-butenyl), which are strongly favourable for potential health benefit introgression. The introgression of three small segments (QTL-1 LG2, QTL-2 LG5 and QTL-3 LG9) of the *B. villosa* genome, each containing a QTL into broccoli genetic background, is done through marker-assisted selection. The isothiocyanate-enriched broccoli had 80 times ability to induce the quinone reductase enzyme in comparison to normal broccoli.

1.8 Antinutrients in Vegetable Crops

Faba bean (*Vicia faba* L.) contains condensed tannins that reduce the value of the produce. The effects of these compounds are the following: (1) bind minerals K, Mg, Ca, Fe and Zn; (2) reduce the activity of the enzyme trypsin and other closely related enzymes that help digest protein; (3) interfere with cells lining the gastrointestinal tract causing acute symptoms, can bind metals and some vitamins and can be toxic; (4) form complexes with iron, zinc and copper that reduces mineral absorption; and (5) inhibit acetyl cholinesterase activity, which impairs nerve transmission and can damage cell membranes. Although some processing practices like soaking and boiling of seeds in water before consumption reduce the tannins to some extent, genetic removal or reduction is an appropriate strategy. For this, studies have been done and two unlinked and complementary genes *zt-1* and *zt-2* were identified to be linked with low-tannin phenotype. Gutierrez et al. (2020) identified a bHLH transcription factor *TRANSPARENT TESTA8* (vf*TT8*), encoding a basic helix-loop-helix (bHLH) transcription factor, as the candidate for *zt2*. Zanotto et al. (2020) reported that the seed coat phenolic profiles of *zt1* and *zt2* genotypes were similar but distinct for flower tissue, suggesting that the gene action results in some different end products of the phenolic biosynthetic pathway. These genes have pleiotropic effect for white-flowered plants. A sequence characterized amplified repeat (SCAR) marker linked to the *zt-2* gene was identified. One of the genes controlling the absence of tannins, which is associated with increased protein levels and reduced fibre content of *faba* bean seeds, should facilitate the development of tannin-free *faba* cultivars (Gutierrez et al. 2008). The major antinutrients present in different vegetables and their effect on health are given in Table 1.13.

1.9 Bioavailability Studies on Biofortified Vegetables

Morris et al. (2008) studied calcium bioavailability from biofortified carrot and reported that the fractional absorption of Ca from the control carrots was 48.8% for females and 56.9% for males, compared with 42.1% for females and 43.8% for males for the sCAX1-expressing carrots. Although fractional Ca absorption is lower in the sCAX1-expressing carrots, the total Ca absorbed per 100 g of fresh carrots is 45.9% higher for females and 38.7% higher for males from the sCAX1-expressing carrots. Therefore, the sCAX1-expressing carrots contain more bioavailable Ca in both the mouse and human models. Horvitz et al. (2004) also reported the positive role of lycopene intake from red carrot over the consumption of white carrot, and Talsma et al. (2016) had similar observations from yellow cassava to improve beta-carotene level in human subjects from Kenyan region. The studies showed that the genetically engineered vegetable crops can help overcome nutritional deficiencies,

Table 1.13 Antinutritional compounds in different vegetables and their effect on health

Antinutrient	Dietary source	Effect
Phytic acid	Legumes	Binds minerals K, Mg, Ca, Fe, Zn
Trypsin inhibitor	Legumes and potato	Reduces the activity of the enzyme trypsin and other closely related enzymes that help digest protein
Haemagglutinin, e.g. lectin	Legumes	Interferes with cells lining the gastrointestinal tract causing acute symptoms; can bind metals and some vitamins; can be toxic
Polyphenolics, tannins	Beans	Form complexes with iron, zinc and copper that reduces mineral absorption
Cyanogens or glycoalkaloids	Cassava, peas, beans	Inhibit acetyl cholinesterase activity, which impairs nerve transmission and can damage cell membranes

such as the following: (1) carrots containing increased Ca levels may boost Ca uptake, reducing thereby the incidence of Ca deficiencies such as osteoporosis; (2) fortified transgenic lettuce with zinc will overcome the deficiency of this micronutrient that severely impairs organ function; (3) folate deficiency, which is regarded as a global health problem, can also be overcome with transgenic tomatoes with folate levels that provide a complete adult daily requirement; and (4) transgenic lettuce with improved tocopherol and resveratrol composition may prevent coronary disease and arteriosclerosis and can contribute to cancer chemopreventive activity.

1.10 Conclusion

The breeding of vegetable crops for quality traits needs adequate attention to meet the diverse need of consumers' taste, health and nutrition. For this, identification of vegetable crops for target nutraceuticals and development of holistic programme by PPP mode with breeder-health expert participation are important requirements. However, the laboratory analysis for quality traits needs to be strengthened since these traits need proper protocols and medium- to high-end laboratories. At initial stage, it is essential to introduce nutrient-rich potential vegetable crops from world over. Also, pre-breeding has shown potential in broccoli and cucumber and marker-assisted breeding in orange cauliflower. Thus, the exploitation of wild species and landraces for discovery of genes/QTLs for nutraceuticals/nutrients is essential. The use of molecular tools in conjunction with conventional breeding for developing vegetable varieties high in nutraceuticals needs emphasis. '*Omics*' and gene editing approaches need to be explored to understand complexities of nutraceutical biosynthetic pathways to tailor them as per requirement.

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2 New Systems of Vegetable Production: Protected Cultivation, Hydroponics, Aeroponics, Vertical, Organic, Microgreens

Brahma Singh

Vegetables, perfect definition yet to come, are edible plants whose parts or whole plant is used as uncooked (salad, desserts, garnish, snack, etc.) or cooked foods. Before farming, humans were hunters and food gatherers. They foraged plants and started their cultivation as an essential part of food, which over the centuries has now developed much-in-demand sophisticated plant sciences, vegetable science being one of them. This vegetable science has developed not only high-yielding nutritious very large number of vegetable varieties/hybrids for different climates, regions, and conditions but also technologies to combat climate change, suitable for controlled environment for their production during on and off season as well as during adverse weather. Vegetable varieties have been evolved with high nutrition through conventional plant breeding and molecular breeding (biofortification) to suite several new production systems.

The medium of production of vegetables had been fertile soil only. But with the discovery of Hoagland and Snyder (1933), it was found possible to grow vegetables without soil or in soilless medium. Decades of research has made it possible to grow vegetables not only in space but commercially on earth also without soil. Growing vegetables under protection or modified environment with or without soil as a medium of production in this chapter is termed as one of the new systems of vegetable production, which have been explained here briefly.

The prevalent systems of vegetable production are as follows:

B. Singh (✉)
Brahma Singh Horticulture Foundation (BSHF), New Delhi, India

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- Open-field cultivation in traditional way—natural farming and organic farming.
- Intercropping of vegetables—vegetables are intercropped with other field crops like wheat and radish/turnip, sugarcane and okra, maize and pole-type beans, and several others.
- Protected cultivation: Protected cultivation involves modification of the natural environment to achieve modified microclimate surrounding the plant partially or fully to suit its requirement for better production. Protected cultivation can be a comprehensive system of controlled environmental vegetable production in which all aspects of the natural environment are modified for maximum plant growth and economic return. Land and water requirement is minimized under protected cultivation to yield plants better by following two major components of the technology.

  Engineering: It deals with structures involving frames, cladding materials, farming beds, irrigation system, tools, implements, and other engineering inputs, which ensure optimal light, air temperature, water, and plant growth requirements. Modern computer and information technologies such as robots, drone, and others are finding essential place in protected farming. This leads to higher yield and quality produce during on and off season or round the year increasing input (other than planting material) use efficiency.

  Crop Production Technology: It involves the development of high-yielding varieties/hybrids of crops suitable for protected cultivation and economical, eco-friendly, and profitable production protocols.

Popular protected vegetable cultivation technologies in India are as follows:

2.1 Plastic Mulches

Plastic mulches are mainly used for weed control, to increase soil temperature, and to keep soil moist resulting in reduction in the use of irrigation water. The most preferred mulch is transparent (clear) and black, although a wide variety of shades and colours are being used for specific purpose. World over, now double-colour plastic mulch, viz. silver + black, blue + black, yellow + black, white + black and red + black, is used and tested in vegetable crops. Early crop, quantitative economy in water and nutrient (fertigation), shaving on deseeding/chemical weeding, and healthy and higher hygienic produce are the conspicuous benefits of plastic mulch. Biodegradable plastic mulch would be common in near future. Organic matter wherever available is used as mulch.

2.2 Plastic Tunnels

Plastic tunnels are getting popular in the country for production of different vegetables and other crops for main cropping season, off season, early crop, nursery raising, etc. These are also called grow tunnels typically made from a frame and covered in polyethylene or biodegradable claddings, usually semicircular, square, or elongated in shape. The interior heats up because incoming solar radiation from the sun warms plants, soil, and other things inside the building faster than heat can escape the structure. There are mainly following three types of plastic tunnels in farming:

1. **Low tunnel**: These are becoming popular to raise early cucurbits, mainly zucchini, besides raising early nursery and crops with low canopy. In Rajasthan, low tunnels are in use to save crops from frost on a large scale:

Low-tunnel nursery production

Naturally ventilated polyhouse (NVPH)

Vegetable nursery—Leh—in solar greenhouse

2. **Walk-in tunnel**: These are with greater height and width than low tunnel, facilitating crop production operations within the tunnel.
3. **High-roof tunnels**: Their height and width are more than walk-in tunnels and equipped with ventilation and cooling devices, etc.

2.3 Naturally Ventilated Polyhouse (NVPH)

Generally, the following three types of naturally ventilated polyhouse popularly known as greenhouses with different claddings and inside provisions are seen throughout the country. Tomato, cherry tomato, capsicums, and cucumber are generally grown under NVPH. These are being promoted by providing subsidy.

1. **Single-span green/polyhouse**: These green/polyhouses can only be used during winter months in India (November–March) or during low-temperature period for vegetable production and nursery raising. Naturally ventilated green/polyhouses with a total central height of 5 m in single span and side ventilation of 3 m, without any provision of roof ventilation, are in use.
2. **Multi-span NVPH**: NVPH with a central height of 6.5 m, gutter height of 4.25 m, side ventilation of 3.5 m, and roof ventilation of 1.0–1.5 m in multi-span is made for raising vegetables and others. Three crops of parthenocarpy cucumber and cultivation of tomato, cherry tomato, and capsicum for a period of 8–9 months or more can be taken in such structures almost throughout the country.
3. **Green/polyhouses with pad and fan system**: Polyhouses having pad and fan system for cooling or lowering temperature are also promoted. They are fabricated with gutter height of 4.5 m having common side ventilation and top ventilation. Such structures are clubbed with exhaust fans and cellulose cooling pads of 1.8 m in height with 150 mm thickness to aid in cooling the greenhouse environment. It adds to the cost, making such polyhouses expensive both in manufacture and running cost on power.

Above structures have helped farmers to raise certain vegetable crops round the year besides high yield and healthy seedling/graft multiplication.

2.3.1 Net Houses

Farmers are using simple structures like the net (both insect-proof and shade) houses for production of vegetables, their nurseries, etc. throughout with lot of technology inputs in these. Net houses are simple structures and affordable with reasonably better returns. Net houses are common in Punjab state of India.

2.3.2 Rain Shelters

Rain shelters, common in the state of Kerala, with or without net are common for vegetable production in places of high rainfall where it was not possible to grow vegetables during rainy season.

2.3.3 Climate-Controlled Greenhouse

Greenhouses with manual or mechanical/automation climate controls are there for production of particular crop/crops round the year. These are input intensive.

In addition to the above, in specific places with unique/unusual climatic conditions, different plant-growing structures are being used such as trench cultivation of vegetables in Ladakh.

Needless to emphasize that present-day modern as well as traditional agriculture practices require large land, water, and energy resources from the planet earth, which unfortunately being finite are fast diminishing and would not freely be available for farming in near future. Another problem is fast urbanization resulting in long-distance transportation of vegetables, short shelf life, and highly perishable commodities. Besides adequate availability of land near the consumption centres like metro-cities, intensive cultivation of vegetables is taking toll on soil health, fertility, and productivity. To overcome these, better methods of vegetable production with ease and comfort, near the place of consumption, have been tried and standardized. Some of them are covered in the following pages.

2.4 New Systems of Vegetable Production

New systems of vegetable production are being added with the incorporation of advancement of technologies in different scientific fields. Some of the partially visible/impacting vegetable production systems have been mentioned in the following pages. The new systems of vegetable production are as follows:

2.4.1 Retractable-Roof Greenhouse

Retractable-roof greenhouses are climate/area specific. It is a combination of natural and controlled environment for production of crops in greenhouse. First such structure was seen in the early 1990s. Roof designs are still being improved and standardized; there is a lack of understanding of the positive impacts of retractable-roof greenhouses on plant health, growth, crop management practices, and subsequent production costs/savings. Retractable-roof greenhouses appear to optimize both photosynthesis and levels of beneficial plant stress to ensure that it develops the strength, disease, and insect resistance not present when plants are grown inside conventional greenhouses. Retractable-roof greenhouses have been shown to help prevent many of the problems of field- and container-grown plants by protecting leaves and roots from environmental extremes such as excessive or insufficient cold, heat, rain, or wind and by preventing disorders associated with insufficient transpiration and the resultant lack of water stress typical in conventional greenhouse environments. This is possible because retractable-roof greenhouses can create an outdoor, greenhouse, and modified greenhouse environment simply by the positioning of the roof, walls, and curtain systems.

Data has shown that clear poly films used for retractable-roof greenhouses (about 25% shading) are more effective at preventing heat build-up in a container compared to either no roof or 50% black shade cloth. Plant responses in retractable-roof greenhouses include stronger root systems, reduced internode lengths, thicker cuticles, fewer root and foliar diseases, fewer insect pests, and less stress and shock following transplanting. Chemical fungicide, growth regulator, and pesticide applications have been reduced by 10–100%. Management has an improved ability to time the crop. Growers of outdoor crops have found benefits including up to a 50% reduction in crop production cycles and about a 50% reduction in summer water usage. Retractable-roof greenhouses will cause a rewriting of crop management strategies, as well as guidelines for how greenhouses are built and where they are built (Vollebregt 2004).

Retractable-roof greenhouses can be seen commonly in Canada. In India, these greenhouses are being demonstrated. Retractable-roof greenhouses have future in India as and when they become affordable by progressive farmers instead of companies.

2.4.2 Soil-Free Cultivation: Nurseries and Crops

It is evident from crop production practices mentioned under protected cultivation above and elsewhere that soil as a medium of production of vegetables is essential, but it is not so. It is a medium meeting certain essential requirements of plants/vegetables. As we see below, the fundamental process of food, feed, fodder, or other crop production is *the photosynthesis*:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

$$\text{Carbon dioxide} + \text{Water} \rightarrow \text{Carbohydrate} + \text{Oxygen}$$

In above reaction which is universal basis of biomass multiplication, soil does not figure anywhere which means *plants can grow without soil* provided that the major roles of soil, like providing support and nutrients to the production of plants, are replaced/substituted. That is what is happening in new systems of vegetable production, where support and nutrients are being made available to the plants without the help of soil. This phenomenon was demonstrated by Hoagland and Snyder in 1933. Over the years, it was experimented and standardized to be commercial during the twenty-first century.

Now, the essential elements for plant growth are the following:

Macronutrients: Carbon (C), hydrogen (H), and oxygen (O) are available in nature/atmosphere. Nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S) are required in large quantity, comparatively.

Micronutrients: Manganese (Mg), boron (B), iron (Fe), copper (Cu), zinc (Zn), molybdenum (Mo), chlorine (Cl), nickel (Ni), cobalt (Co), sodium (Na), and silicon (Si) are required in very small quantity.

Above elements are available in liquid form with long shelf life for different crops and their stage of growth. One can make the nutrient solution at farm or at home.

Above nutrients are applied to the inert medium (solid) or water as per requirement of the crops to yield better in methods of supply of nutrients. The technique is termed as hydroponics.

2.4.2.1 Hydroponics

The technique uses inert solid medium or water medium to supply the required nutrients to plants.

Solid Inert Medium

Solid inert media such as sand culture, gravel culture, or rockwool culture, clay ball, and others are used for raising plants and feeding roots. Medium other than soil which is an inert material is known as solid inert medium. This medium has good porosity, water-holding capacity, and other good properties. The main contribution of inert medium is to provide support to the plant.

The different types of popular growing media are as follows:

1. *Coco coir*: In India, it is becoming a popular soilless medium. It is inert and has excellent moisture-holding ability. It is made from the husk of coconut shell. It is available in small compressed blocks, which expand 6–8 times in volume on addition of water. Coco coir has good aeration property. It has disadvantage too of breaking down after several uses and takes time to drain out excess water.
2. *Hydroton*: It is an expanded clay product. It has a porous structure, which makes it easy to absorb water and other nutrient solutions. It provides ease in exchange of oxygen with roots. It is a pH-neutral product in which it is good to grow crop. It is the most versatile growing medium in soilless crop production.
3. *Perlite*: It is made by heating; it expands like popcorn. It is a lightweight inexpensive growing medium made of inert material. It cannot be used alone for ebb and flow because it floats away or moves during the flooding cycle. It is porous and has good water retention properties.
4. *Vermiculite*: It is a lightweight natural mineral used as growing media in soilless cultivation. Through this, soil aeration is better which helps to improve soil structure and increases water and nutrient retention. Vermiculite is rot a resistant growing medium.

5. *Peat moss*: It is the most common medium in some countries for growing plants. It is a dark-brown fibrous organic material. The chief advantage is that it can hold moisture several times its weight and releases to the plant roots slowly in required amount. This is made from sphagnum moss that has been decomposed in peat bogs over thousands of years.
6. *Sawdust*: It is made from sawing wood. It is 100% organic, eco-friendly, and easily available soilless growing medium but has short shelf life.
7. *Rockwool*: Rockwool is used especially for insulation and soundproofing. It is a soilless growing inorganic medium, which is made into matted fibre. It is noise resistant as well as fire resistant and can withstand extremely high temperatures. It is more expensive than other media and different from other insulating materials.
8. *Coarse sand*: Sand particles having a diameter of 0.5–1 mm are an excellent medium and common in soilless vegetable production. Drainage and aeration are better in sand medium.
9. *Pea gravel*: Gravels of pea seed size are used, which provide improved drainage. There are no weeds and soil erosion.

The most common one in India is cocopeat which is available as loose, bricks, and in grow bags and other forms. Vermiculite, rockwool, peat moss, coarse sand, sawdust, paddy husk, cocopeat, pea gravel, clay balls, and some others are available locally.

Water Medium Culture

This is popularly known as hydroponics culture. Plants are grown in water nutrient solution. Plant roots remain suspended directly in the solution. It is classified further into

1. *Circulating methods (closed system)/continuous flow solution culture*
   It can be in the following two forms:
   (a) Nutrient film technique (NFT)
   NFT consists of a shallow channel/trough with a slope of 0.3–2%. Nutrient solution is continually pumped at the elevated end, which flows in trough wetting the roots continuously. Plant roots lie wet inside the bottom of the trough. Flowing nutrient solution is drained back to water nutrient reservoir where periodically it is supplemented.
   (b) Deep flow technique (DFT)
   This is like NFT. Drainage channels 4–6 cm high with nutrient solutions are used for growing plants. Roots of the plants remain submerged in the continuously flowing nutrient solution. In comparison to NFT, the flowing nutrient solution depth more fully submerges plant roots. Rest it is like NFT.
   In both the systems, frequent or continuous attention is required to ensure the continuous flow of the nutrient solution. If flow by any means is stopped, plants get desiccated. Auto control in both the systems is possible. Both the systems are popular with several innovative modifications.
2. *Non-circulating method (open systems)/static solution culture*

In this method, the nutrient solution is static and not circulated. This nutrient solution is used only once. On change of its pH and EC, the nutrient solution is changed. It can be used in the following or some more ways:

(a) Root dipping technique
In this method, first plants are grown in small pots having little growing medium. These pots are submerged in nutrient solution. Only lower 2–3 cm portion of pots is submerged in nutrient solution. This facilitates dipping of some roots in the solution for absorption of nutrients, and rest of the roots hang in the air for oxygen absorption.
(b) Floating technique
In this technique, shallow containers with 10 cm depth can be used. Well-established plants in small pots are fixed to float, on the nutrient solution filled in the container, with the help of a Styrofoam sheet or any other light plate. Nutrient solution is periodically replenished and aerated.
(c) Capillary action technique
Pots of different sizes and shapes with holes at the bottom are used. Fill these pots with an inert medium, and seedlings/seeds are planted. These pots are placed in shallow containers filled with the nutrient solution. Nutrient solution reaches plants through inert medium by capillary action. Frequent aeration is a must in this technique.
(d) The ebb and flow system
This system works by flooding and draining the grow trays with nutrient solution. Drained nutrient solution goes back into the reservoir. A submerged pump connected to a timer is used. Depending on the size and type of plants, temperature, humidity, and type of growing medium used, the timer is set to come on several times a day.

To suite the local conditions, there are many variations on these basic types of systems:

Home Garden Hydroponics (NFT) on mint in open, Delhi, May 2021

Italian Basil growing in Hydroponic

Advantages of Hydroponics

There are several advantages of hydroponics; some of the these are listed below.

- There is an increase in yield per unit of water, space, and energy used.
- Space utilization is maximized adopting vertical growing method.
- It uses 70% less water; hence, increased yield per unit of water, space, and energy are there.
- Since soil is not used as a medium, the problem of soil-borne pathogen/pesticide/herbicide residue in produce is not there.
- Soil is not the medium of growing plants in hydroponics, so overexploitation of soil is not there.
- Hydroponics are generally used under controlled conditions; hence, danger of combating climate change and seasonality is not there.
- Great advantage is there of using nonproductive land/soil or wasteland and rooftops for crop production.
- Crop production under artificial light and in space possible.
- This allows for growing plants underground/under the oceans and in space besides aboveground—plant-growing portable shipping containers.
- It allows humanity to live anywhere.

- Education on plants to children in big cities is an added advantage.
- It provides natural antioxidant-rich fresh horticultural produce with uniform quality produce.

Disadvantages of Hydroponics

- Initial cost of hydroponic system is high.
- Regular and strict monitoring of feeding, nutrient solution, and growth is necessary.
- Hydroponics systems are power/electricity dependent. Long interruption in power supply would lead to crop failure.
- Harmful microorganisms that are water based can creep in rather easily.
- Without technical expertise, growing a hydroponic garden is not possible.
- Plants react quicker to changes in the environment.
- Hot weather and low oxygenation of roots may affect production.
- Maintenance and input supplies in home-scale hydroponics are an issue.
- In commercial hydroponics, one must compete in the market with traditionally grown vegetables. Taker of hydroponics produce at present is a section of a society or hotels of repute.

2.4.2.2 Aeroponics

Aeroponics is the soilless, inclusive of aggregates, crop production, wherein plant roots are suspended in dark encloser and misted or fogged periodically adequately with standard nutrient solution. In other words, aeroponics consists of enclosing the root system in a dark chamber with provision of misting/fogging nutrient solution required for the crop. It is used successfully in tomato, lettuce and other leafy vegetables, and cucumber (Gopinath et al. 2017).

To meet the increased requirement of high-quality potato seed tubers, aeroponic systems have been established (Kang et al. 1996). Korea has successfully used aeroponics for potato seed tuber production (Kim et al. 1999). It is getting popular in India for potato mini seed tuber production or breeder seed tuber production.

Aeroponics are more user friendly. Plant roots are all separated and suspended in the air in dark, facilitating stolen development to produce seed tuber free of soil and soil-borne pathogens. There is ample supply of oxygen to plant roots. The harvesting of crops is simple. Vegetable crops like potato, yams, rhizomes, tomato, lettuce, and leafy vegetables are being commercially cultivated in the aeroponic system. The system is becoming popular.

Like any other systems of crop production, aeroponics crop production has certain advantages and disadvantages. Important ones are listed below.

Advantages

1. Less fertilizer/nutrients are required as the feeding of roots is through mist or fog.
2. Less water is required as feeding of nutrient and water is through spray.
3. It is cost effective on account of less water and nutrient requirement.
4. There are reduced diseases and damage due to better care and protective environment.

5. It ensures healthier and faster growth since the root region has enough oxygen and required nutrients.

Disadvantages

1. Large-scale production and maintenance are expensive.
2. Ordinary farmers will struggle to manage the sophistication involved.
3. Mister spray nozzle/heads tend to clog and not produce mist when needed the most.

Compared to conventional methods or to other soilless methods of hydroponics, aeroponics offers the potential to improve production and reduce costs. Vertical farming is easier by using aeroponics. Aeroponic technology with different modifications is being researched upon.

2.4.3 Aquaponics

With same input resource of water and nutrients, production of fish and vegetables is possible using aquaponics. With same inputs, added return on account of vegetable production is the advantage in comparison to aquaculture as it combines aquaculture with hydroponics. Aquaponics results in effective utilization of fish pond water and its nutrients for production of vegetables/plants simultaneously with added returns on input resources. Plants act as bio-filter for the recycled water to fish pond. Fish produce ammonia (NH), which is converted to nitrate (NH_3). The water is sent to plants, which absorb nutrients that they need. The water is returned to the fish pond.

Farmers combined rice/paddies with fish—to grow both in a field is also a form of aquaponics and is much cheaper as is practised in natural environment.

2.4.3.1 Use of Nanotechnology

The application of nanotechnology in vegetable production systems has great potential to minimize the inputs quantitatively and effectively. Nano-fertilizers and nanomaterials can provide nutrients and crop protection for plants much more effectively. Precision farming is benefited from nano-sensors. The available nanotechnology approaches in soilless farming include:

1. Nutrient's nanoparticles to minimize nutrient losses and improve nutrient uptake and bioavailability in plants
2. Nano-sensing for providing real-time detection of pH and temperature, as well as quantifying the amount of the nutrient, allowing desired conditions' control
3. Nanoparticles' incorporation to improve the quality of substrate culture as crop cultivation growing medium

Potential of nanotechnology applications in soilless farming includes the following:

1. Plant trait improvement against environmental disease and stress through nanomaterial application
2. Plant nano-bionics to alter or improve the function of the plant tissue or organelle
3. Extending the shelf life of vegetables by impregnating nanoparticles on the packaging or other preservation methods (Maluin et al. 2021)

Soilless production combined with nanotechnology can provide a more sustainable and productive alternative to conventional farming. It has great potential to attract youths in vegetable production commercially and children and elderly persons including housewives in new-age home gardening.

2.4.4 Container Farming

Container farming is a method of farming by using shipping containers as a substitute for farmlands. These are on wheels, facilitating transport of them to consumers. Shipping containers are placed at flat and stable ground, where water and power are available for production of crops. Hydroponics coupled with vegetable production in vertical controlled environment with or without the use of sensors is used in container vegetable production. Container farming is one of the best hydroponic methods of vegetables that are nutritive and free of harmful chemicals. Natural environmental factors like temperature, intense sunlight, or pollution do not interfere with vegetable production. Container farming models for leafy greens have been developed and commercialized.

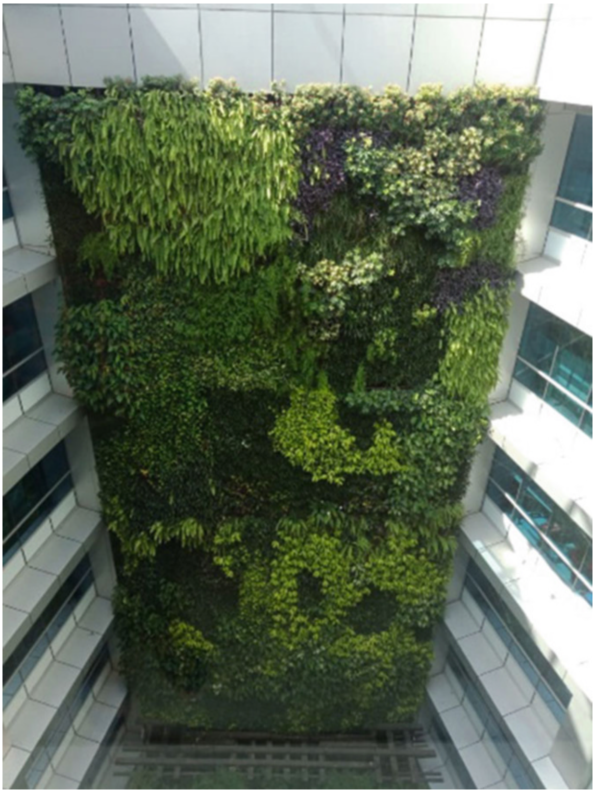
2.4.5 Vertical Farming (VF): Food Factories

Vertical farming is the practice of growing crops in vertically stacked layers. Grow beds are made in different orientations such as towers, with multiple layers of beds one over the other. Vertical farms use soil, hydroponic, or aeroponic growing methods. If saving space is of utmost importance, hydroponic methods as a growing medium instead of soil allow for reduced weight and lower water requirements by up to 70%. Soil and soil mix are also used as a production medium. Turmeric and ginger vertical farming in India makes use of soil, sand, and manure mix as a medium of production with desirable results. Hence, vertical farming is “farm up” rather than “out”. It is a revolutionary approach to produce high quantities of nutritious and quality fresh food/fodder/other crops from a small area/space all year round, without relying on huge labour, favourable climate, good soil, or water. It has the potential to ensure the sustainability of our bulging cities/urban areas by addressing food security. It minimizes land use and can be in high population density area. The two places, where vertical farming is common, are as follows.

1. **Indoor farming** is production of plants or crops on commercial scale entirely indoors. This method of crop production uses modern methods such as

hydroponics and utilizes efficient artificial lights for photosynthesis to provide plants with required nutrients and light. Certain horticultural crops such as fruits, vegetables, and herbs do well indoors. Commercial production of foods indoor is termed as production in food factories. Available space, vertical and horizontal, is efficiently utilized. It requires many inputs as except seeds/seedlings most of the things are substitute to natural factors of farming.

2. **Urban agriculture** is also known as urban farming, or urban gardening or underground farming. It is the practice of cultivating, processing, and distributing food/vegetables or ornamental plants in or around urban areas. Crop production occurs in peri-urban areas as well, and peri-urban vegetable production may have different characteristics. Besides vegetable production, urban agriculture covers predominantly horticulture along with animal husbandry, aquaculture, urban beekeeping, and others. Such food production practices occur in peri-urban areas as well:



Green wall—vertical garden

Lettuce in hydroponic VF at Gurugram

2.4.5.1 Features of Vertical Farming

Vertical farming in general has the following features:

- All-time fresh food availability: 24 h a day, 365 days a year.
- Protection from unpredictable and harmful weather and insects/birds.
- Reuse of water and nutrients collected from the indoor environment.
- Minimizes use of major inputs, fertilizers, water, and chemicals.
- Prevents crop loss due to shipping or storage or long transportation.
- Provides ultimately a proud feeling among farmers of being technocrat farmers.
- It is resilient agriculture.
- Vertical indoor farming is poised to become a common and efficient system of food production. System automation is the key to unlocking its full potential of VF.
- The world is changing. Food travels thousands of kilometres to our dining table. We are short of space, energy, and freshwater. We are multiplying and eating to be obese. Vertical farming could be one of the remedies.

2.4.5.2 Advantages of Vertical Farming (VF)

VF has several advantages. Some of them are listed below:

- It offers reliable harvests as intensive care is taken during crop production.
- Low labour costs, low water and nutrient usage, reduced washing and processing, and reduced transport costs minimize the overheads and inputs in VF.
- Now, a wider range of crops can be grown in vertical farming.
- Vertical farming is a fully integrated technology.
- Required air, nutrients, water, light quality, and other inputs are provided.
- It increases the available area in tiers.

2.4.5.3 Limitations of Vertical Farming

The following limitations are there at present in adopting vertical farming:

- Social resistance is likely as people may not accept the change in traditional horizontal farming.
- Growing food indoors requires more energy, effort, and certain resources.
- It is comparatively more expensive because of multiple vertical growing beds.
- Vertical greenhouse is costlier than a normal greenhouse.
  – Unaffordable in dense and expensive urban localities because of high cost of land and structures.
  – Break-even point may well be an estimated 6–7 years because of initial high investment.
- There is inability to produce all types of crops vertically.
- Final produce is costlier for the end consumer.
- Recycling and utilization of city waste technology are yet to take off.
- Organic certification: It is organic with inorganic inputs.
- Pollination need—crops requiring cross (insect) pollination are to be pollinated by hand or robot.

2.4.6 Precision Vegetable Production

Precision farming is a popular new concept in production, particularly in vegetable crops. It can be defined as a crop production system designed to optimize production by using advanced crop production technology, available crop information, and management practices by doing the **right operation at right time in right manner and right quantity**. Precision vegetable farming begins with crop planning, which includes all operations such as tillage, planting, fertilizers, and other chemical applications, harvesting, as well as post-harvest processing of the crop. A few technologies used in precision vegetable production include integrated nutrient management, protected cultivation, post-harvest technology, micro-irrigation, sensors, and fertigation.

A truly comprehensive approach to precision vegetable production must cover all the following phases of production from planning to post-harvest:

- To increase productivity, improve product quality, allow more efficient chemical use, and conserve energy and water, information technology and management are combined into a production system.
- Field scouting, field mapping, variable rate control, yield mapping, and post-harvest processing can readily be adapted to vegetable crop production. However, the technology related to precision farming needs refinement to realize benefits (Kalia 2005).
- Success of precision farming lies in the concept of doing the right thing in the right place at the right time.
- Technologies like artificial intelligence (AI), robotics, sensor technologies, geographical positioning system (GPS), and geographical information system (GIS) are being utilized for precision vegetable farming to improve production and quality of vegetables.

2.4.7 Smart Technologies in Vegetable Production

Use of blockchain, AI, machine learning, robotics, Internet of Things (IoT), edge computing, 5G, and drones in vegetable production is termed as smart technologies in vegetable production. It is a management concept focused on providing the vegetable industry with the infrastructure to leverage these and upcoming advanced technologies. The components of smart vegetable production are the following:

Sensors: soil, water, light, humidity, temperature management
Software: specialized software solutions that target specific farm types or applications of agnostic IoT platforms
Connectivity: cellular, LoRa
Location: GPS, satellite

Contrary to trial-and-error traditional farming, smart vegetable production is 95% science.

2.4.8 Microgreens

Microgreens are vegetable seedlings with one or two true leaves, not sprouts or shoots or tender edible part of a plant, and are a newly emerging food that is potentially a dense source of minerals and vitamins. The seeds used to grow microgreens are same as used to grow crops like vegetables, herbs, and leafy greens. This stage of seedlings or microgreens is reported to be rich in nutrition and flavour and free of pesticides and pathogens in comparatively healthy state. They taste better when used as raw or cooked. They are now considered a specialty genre of greens, good for garnishing salads, soups, sandwiches, and plates. They range in size from 1 to 3 in. (2.5–7.6 cm), including the stem and leaves. The average crop time for most microgreens is 10–14 days from sowing/seeding to harvest.

There are different stages of microgreens such as pico-greens, nano-greens, microgreens, baby greens, and greens. Comparatively, they are rich in nutrition than their mature counterpart/crops.

The nutrient contents of lettuce and cabbage microgreens grown hydroponically (HP) and on vermicompost (C) were assessed and compared to each other as well as to the nutrient contents of store-bought cabbage and lettuce (mature vegetables). Of the ten nutrients examined (P, K, S, Ca, Mg, Mn, Cu, Zn, Fe, Na), C cabbage microgreens had significantly larger quantities of all nutrients than HP cabbage microgreens (p-values <0.00321) with the exception of P; C lettuce microgreens had significantly larger quantities of all nutrients than HP lettuce microgreens (p-values <0.024) except for P, Mg, and Cu. Compared to the mature vegetable, C or HP cabbage microgreens had significantly larger quantities of all nutrients examined (p-values <0.001) and C or HP lettuce microgreens had significantly larger quantities of all nutrients except for Ca and Na (p-values <0.0012). Results of this study indicate that microgreens grown on vermicompost have greater nutrient contents than those grown hydroponically (Weber 2016).

2.4.8.1 Crops for Microgreen Production

The selection of the crop is based on seedling colour, texture, flavour, and demand of the produce market. The most potential microgreens are found in the vegetable crops belonging to the families Brassicaceae, Chenopodiaceae, Amaranthaceae, and Apiaceae. Few crops belonging to the family Fabaceae (vegetable pea) are also suitable for microgreens. Various colour shades are available in these families due to the presence of various pigments like chlorophyll, carotenoids, anthocyanin, betalains, and others. Chlorophyll provides lush-green to deep-green colours to microgreens. Carotenoids provide yellow colour to microgreens. Anthocyanins provide purple colouration to microgreens belonging to the families Brassicaceae and Apiaceae. Betalains are mainly found in plants belonging to the family Amaranthaceae. Chenopodiaceae provides vivid red-pink to yellow colours. Microgreens from Brassicaceae and Apiaceous have distinct flavour and make them suitable for garnishing various dishes. Microgreens of chickpea have sour taste, whereas fenugreek is bitter in taste.

2.4.8.2 Production of Microgreens

Growing media: Microgreens are produced in container, basket, or pot containing growing media. Wide range of media are available in market like coir, wood fibre, bark, paper fibre, peat moss, perlite, rockwool, cocopeat, vermiculite, vermicompost, and sphagnum peat for production of microgreens. Selection of media should be done carefully to provide optimum germination conditions and local availability. Microgreens can be raised in sterilized sand with or without additional liquid fertilizers or vermi-wash. At the Indian Institute of Vegetable Research, Varanasi, a mixture of cocopeat, vermiculite, and perlite in the ratio of 2:1:1 was found better for the growth of microgreens. Microgreens are prone to pre- or post-emergence damping off caused by soil-borne pathogenic fungi. Thus, seeds and medium before sowing should be completely sterilized if it is suspected for containing pathogenic organisms. Some media like vermiculite and perlite are inherently sterile, which do not need any sterilization. Sometimes, seed treatments are advised. Due to very short pre-harvest period, chemical treatment is avoided. Seed treatment with bio-control agent like *Trichoderma harzianum* and *T. virens* is recommended. Recently, hydroponic techniques have been used for the production of microgreens. Research on hydroponics reveals that microgreens produced using nutrient film techniques have higher yield compared to growing on tray containing media.

Seed sowing: Seeds for microgreen production should be collected from known source of known variety. Number of seeds per square inch of growing space can be approximately 10–12 smaller and 6–8 larger, respectively.

Growing condition: Microgreens are commercially produced under protected condition. It requires high light condition, preferably natural sunlight with low humidity and good air circulation. High light levels produce a stronger, longer lasting, and more flavourful microgreens than those grown under lower light conditions or artificial lights. In recent times, light-emitting diode with deferent spectral ranges and intensity has been used to modulate the growth of microgreens. Red spectrum light was found to keep plants short, whereas blue spectrum light fuels vegetative growth and thus encourages height. Sometimes, light-emitting diodes (LEDs) also influence nutritional composition like supplemental green LED that could enhance accumulation of carotenoids, such as lutein/zeaxanthin and β-carotene. Microgreens can be grown in open during growing season and in houses indoor with adequate light.

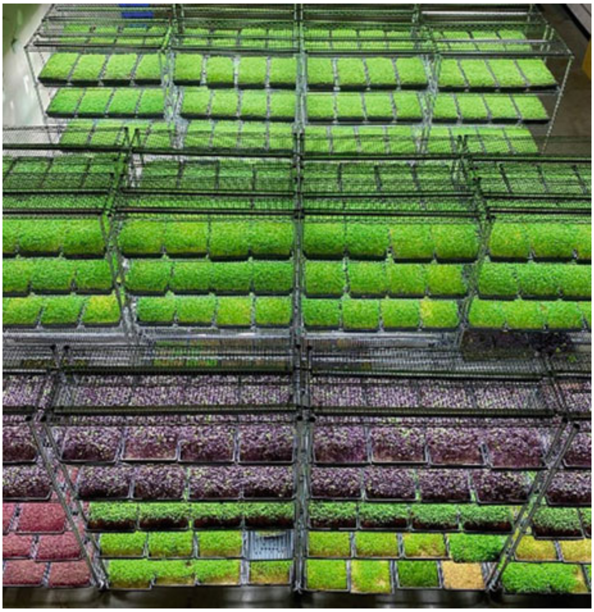
Watering: The growing media should be kept moist but not overly wet. Plastic/glass/fibreglass/other environment-friendly trays should be used for raising microgreens. Ensure favourable temperature of 26 ± 2 °C. After sowing, trays should be gently watered and covered with an inverted slotted tray for 48 h to keep humidity levels high. Water seedlings with sprinklers lightly and carefully twice daily until harvesting. Excessive and inadequate watering is not desirable.

Harvesting: Microgreens are cut along with the stem and attached cotyledons/seed leaves with the help of scissors 7–14 days after germination in tropical climate and slightly longer (14–28 days) in cold weather or temperate region with a height of 2.5–7.6 cm (1–3 in.). The height of microgreens varies from crop to crop and variety to variety and with other environmental conditions. Microgreens, if left for longer, will elongate and lose both colour and flavour. At the stage of harvest, sorting, and delivery, good hygiene practices are followed.

Post-harvest operation: Microgreens are highly perishable with very short shelf life, usually 3–4 days at ambient temperature. After harvest, microgreens are thoroughly pre-cooled for better shelf life. Hydro-cooling could be the cheapest method of pre-cooling for microgreens. Another way to extend the shelf life of microgreens is modified atmospheric packaging. All post-harvest operation should be done in microbe-free environment. Applying the harvesting date on label is advisable. From a local grower's perspective, having a harvesting date on the pack could reinforce the freshness of the product.

Use and safety: Microgreens are usually consumed raw ensuring no loss of nutrients noticed in the use of cooked and processed foods. Unlike cooked vegetables, there are always chances of microorganism contamination in microgreens. Thus, major emphasis should be given on hygiene and sanitary conditions during production to post-harvest operation. Microgreens are used in salads, sandwiches, and soups and for garnishing vegetable and meat dishes. They are being used to garnish Italian and Chinese fast food. It can also be a suitable material for stuffing paratha and other Indian foods. They can go well with pao bhaaji, chole bhature, and other popular street foods. Food safety issues with microgreens may be increasing due to the number of indoor microgreen-growing operations with excessive seed density, low light intensity, low air circulation, or most commonly a lack of good agricultural practice (GAP) and good manufacturing practice (GMP) based food safety procedures. All plants cannot be grown as microgreens due to toxicity concerns. For instance, plants belonging to nightshade or Solanaceae family (eggplants, tomatoes, capsicums, potatoes, etc.) should not be grown as microgreens as they may be toxic.

Microgreens are a promising new food source to satisfy consumers in eating healthy diets (Uyory Choe et al. 2018):



Microgreens

2.4.9 Vegetables and Photovoltaic

Crops are cultivated in between PV arrays and below photovoltaic installations for simultaneous production of food and energy. It is picking up in Gujarat in India. It is co-developing the same area of land for both solar photovoltaic power generation and vegetable production. In India, it is on experimental scale, but in some countries, it has become a commercial practice. Being subsidized for solar panels in India, it has the potential to be popular. The system is popularly known as agri-voltaics or agri-photovoltaics. The coexistence of solar panels and crops implies a sharing of light and land between these two types of production.

Shade-loving vegetables do well in between the photovoltaic panel. Even cucurbits or indeterminate tomatoes like cherry tomatoes can be trained on post or crop nets between poles of the panels by designing appropriate orientation of the post of the photovoltaic panel for light on panel and to the crops like kale, chard, broccoli, cabbage, cucurbits, peppers, tomatoes, *Chenopodium*, fenugreek, coriander, spinach, and others.

Agri-voltaic system (AVS)

2.4.10 Open Rooftop Greenhouse Cultivation

Retractable-roof greenhouses have provision of opening and closing the roof of the greenhouse to release trapped heat or trap the heat by closing. This system facilitates advantages of natural atmosphere and controlled or artificial environment. It adds to the initial cost in building the structure but reduces the recurring cost, particularly the power bill substantially.

Some of the benefits of retractable-roof greenhouses in addition to those listed elsewhere in the chapter are as follows:

- Consistent yields regardless of the weather extremes
- Better price in the market with better quality of produce and shelf life
- Reduction in recurring power expenditure
- Protection of crops from insects using stationary or retractable insect net
  Such greenhouses are popular in Canada. In India, these are coming up for demonstration for adoption.

2.4.11 Vegetable Grafting

Cucurbitaceous and Solanaceous vegetables face several bio-stresses, which are becoming very difficult to manage. Use of resistant rootstock to different bio-stress particularly to root-knot nematodes has been found feasible and economical besides giving pesticide-free produce. Vegetables belonging to Cucurbitaceae and Solanaceae are amenable to grafting mainly for providing resistance against soil-borne pathogens, tolerance to abiotic stress, and an appreciable increase in yield.

Vegetable grafting or grafted seedlings do improve crop productivity arguably at the expense of fruit quality. Grafting is not employed as a method for improving vegetable fruit quality (Kyriacou et al. 2017).

Brinjals/aubergines, melons, sweet peppers, chillies, cucumbers, tomatoes, and squashes can be grafted onto suitable rootstocks. Grafted vegetable plants can have greater vigour and/or more resistance to soil-borne diseases and pests such as root-knot nematodes.

2.4.11.1 Problems Associated with Grafting

Cropping with grafted seedlings is not devoid of problems. Labour, techniques, compatible rootstock, its multiplication, etc. are the major issues. Initially, handling of grafted seedlings for rapid healing for 7–10 days requires intense attention. Development of multipurpose rootstocks, their multiplication, and developing efficient grafting machines and techniques will facilitate adoption of grafted seedlings. Future is for grafted seedlings in certain vegetable crops' production (Kyriacou et al. 2017).

Vegetable grafting at VNR Nursery, Chhattisgarh

2.4.12 Organic Farming/Natural Farming

There is growing sound about organic farming. Farming with organic inputs in open fields or to certain extent in greenhouses is desirable to have healthy vegetables (free of residue of synthetic pesticides as use of organic inputs only in crop production is permitted). Lot many organic inputs to supply plant nutrients and pesticides are cropping up with varied success. Major role of organic farming is to ensure soil, human, and animal health by avoiding excessive use of synthetic fertilizers and pesticides in crop/vegetable production.

There are reports on reduction in crop productivity if organic farming is followed. At the same time, it is reported and hypothesized that organic farming helps to prevent a loss of topsoil, toxic run-off, water pollution, soil contamination, soil poisoning, and death of insects, birds, and other beneficial soil organisms, as well as eliminate pesticide, herbicide, and fungicide residues on food from synthetic fertilizers but at the cost of total quality produce.

Use of vermicompost has picked up considerably in organic farming. Certified organic vegetable products offer high price in the market.

The future success of organic vegetable production would largely depend on supplies of non-chemical effective inputs and proven package of practices for producing vegetables organically. The suitable varieties of vegetables for organic production need to be developed using available and acceptable crop improvement technologies. The use of varieties that are better adapted to local biotic conditions (e.g. biological control of pests and diseases, climatic stress) needs to be promoted. The possibilities to supply nutrients, particularly nitrogen, and suppression of diseases through periodic spray of vermi-wash and similar preparations should be explored experimentally. Use of experimented biopesticides or physical means to minimize yield loss in vegetable production due to insects and pests should be given due attention. Areas (inaccessible) practising organic vegetable production by default need major attention for promotion of organic production.

2.5 Summary

This chapter deals with comparative use of traditional and new systems of vegetable production. Reduced resources, rapid urbanization, perishable nature of most of the vegetable crops, climate change, quality consciousness among consumers, disinterest of youth in traditional vegetable production, booms of digital technologies, and environment concerns have led to several new systems of vegetable production. These systems involve soilless farming (hydroponics, aeroponics, aquaponics, inert medium), precision farming, vertical vegetable farming, urban and preurban farming, etc. with and without the use of digital and mechanical tools and gadgets, nano-inputs, use of tissue culture seedlings and grafts, photovoltaic aid, and retractable greenhouses. This has led to cropping up of container farming, food factories, vertical vegetable farms, and domestic soilless and sun-free home and rooftop home gardens in urban areas, which already have more than 60% of world population. The new systems ensure higher productivity in terms of quantity and quality. Initial cost/infrastructure cost in some of the systems is high, which gets covered in a short period. Production of new class of dessert, the microgreens, has been explained along with protected cultivation, soilless cultivation, and precision production. These systems are picking up in clusters in India.

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Bioactive Nutrients in Vegetables for Human Nutrition and Health

3

Jagdish Singh

Abstract

Vegetables are parts of plants that are consumed by humans as food. They can be eaten either raw or cooked and play an important role in human nutrition, being mostly low in calorie, fat and carbohydrates, but high in vitamins, minerals and dietary fibre and particularly antioxidant vitamins A, C and E. There is an increasing awareness about the advantages of diet rich in vegetables to ensure an adequate intake of vitamins, micronutrients, dietary fibres and antioxidant phytochemicals, and it has been demonstrated that there is reduction in the incidence of lifestyle diseases including cancer, stroke, cardiovascular disease and other chronic ailments with inclusion of vegetables. Phytochemicals (phyto means plant in Greek), also referred to as phytonutrients, are thought to be largely responsible for the protective health benefits of these vegetable-based foods. The phytochemicals, which are part of a large and varied group of chemical compounds, are classified according to their chemical structures, and functional properties are also responsible for the colour, flavour and odour of vegetables, such as broccoli's bitter taste and garlic's pungent odour. Tens of thousands of phytochemicals have been identified, of which flavonoids are the largest, most varied and most studied group of phytochemicals. In fact, more than 6000 flavonoids that occur in plant foods have been described. Research on specific phytochemicals in vegetables and their effects on disease risk is limited; however, studies strongly suggest that consuming foods rich in phytochemicals provides health benefits. Still, it is not known whether the health benefits are the result of individual phytochemicals or interaction of various phytochemicals, and also not enough information exists to make specific recommendations for phytochemical intake. More interdisciplinary work is required that involves nutritional and food

J. Singh (✉)
ICAR-Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh, India

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scientists as well as others from the biomedical field to ascertain the true function of specific phytochemicals.

Keywords

Bioactive nutrients · Phytochemicals · Antioxidants · Free radicals · Carotenoids · Flavonoids · Anthocyanin

3.1 Introduction

Vegetable refers to the edible parts of plants, which are usually their leaves, roots, fruits or seeds. They are a staple food across the world and are mankind's most affordable source for micronutrients, viz. vitamins and minerals needed for healthier diets. Vegetable production provides promising economic opportunity for reducing rural poverty and unemployment and is a key component of farm diversification strategies. Intensified vegetable production has the potential to generate more income and employment than other segments of the agricultural economy. A total of 1097 vegetable species are cultivated worldwide. However, we are familiar with less than 7% of these species. A world vegetable survey has shown that 402 vegetable crops are cultivated worldwide, representing 69 families and 230 genera. Leafy vegetables, of which the leaves or young leafy shoots are consumed, were the most often utilised (53% of the total), followed by vegetable fruits (15%), and vegetables with below-ground edible organs comprised 17%.

Vegetables make up a major portion of the diet of humans in many parts of the world and play a significant role in human nutrition, especially as a source of vitamins (C, A, B1, B6, B9, E), minerals and dietary fibre. Studies have shown that dietary fibre may also improve vitamin and mineral absorption in the body. According to the ICMR-National Institute of Nutrition, Hyderabad, 350 g vegetables should be consumed per day amounting to about 100 kcal to fulfil 5% of the total calorie and 4 g protein requirement.

Vitamin C, also known as **ascorbic acid**, is a water-soluble vitamin. The RDA for adults is 60 mg/day. The best sources of vitamin C are vegetables such as broccoli, cabbage and other green leafy vegetables, peppers, tomatoes, citrus fruits, mangoes, papaya and strawberries. Vitamin C is relatively unstable; it is heat labile, prone to oxidation and lost as a result of cooking foods by immersing them in water. Vitamin C is involved in the repair of tissue and the enzymatic production of certain neurotransmitters. It is required for the functioning of several enzymes and is important for immune system function. It supports decrease in the length of time and severity of symptoms associated with upper respiratory viral infections, promotes phagocytic cell functions and supports healthy T-cell function. It also functions as an antioxidant to support healing at sites of inflammation.

The well-known function of vitamin C related to cancer prevention includes trapping of free radicals and reactive oxygen molecules and protecting against lipid peroxidation, reducing nitrates and stimulating the immune system. The evidence for a protective effect of vitamin C appears to be strongest for cancers of the stomach, upper aero-digestive tract and pancreas. Vitamin C-rich fruit consumption has been associated with protective associations most consistently for lung, upper digestive tract, stomach and pancreatic cancers. There are several reasons why the association between vitamin C and stomach cancer is especially plausible. Vitamin C is known to block nitrosamine formation in the stomach, and supplementation with vitamin C in at least two studies has been shown to decrease the mutagenicity of the gastric juice in humans. For several other sites, including cervical and bladder cancer, the results for both vitamin C and fruit consumption are inconsistent. There is little evidence to support a protective relationship between either vitamin C or vitamin C-rich fruits and cancer of the colon, breast or prostrate.

B Vitamins: B vitamins help store energy and utilise carbohydrates, produce red blood cells, aid in digestion and promote a healthy nervous system. These health benefits translate to less heart disease, lower risk of birth defect, brain function and healthy skin. Vitamins B1 (thiamin) and B2 (riboflavin) are important in normal antibody response. Vitamin B5 (pantothenic acid) promotes the production and release of antibodies from B cells, and deficiency of vitamin B5 results in reduced levels of circulating antibodies. Vitamin B6 deficiency consistently impairs T-cell functioning and results in a decrease in blood lymphocyte counts. Folic acid (vitamin B9) deficiency leads to a decrease in T cells and supports production of red blood cells, which carry oxygen around the body. Vitamin B12 found in animal products inhibits phagocytic cells and possibly T-cell function.

Sources of B Vitamins: Vitamin B1 (thiamin): lettuce, lima beans, spinach beet, greens, squash, Jerusalem artichoke. Vitamin B2 (riboflavin): Brussels sprouts, mushrooms, potatoes, broccoli. Vitamin B3 (niacin): asparagus, corn, artichokes, mushrooms, potatoes, peas, sweet potatoes. Spinach is an excellent source of folate, vitamin B6 and vitamin C. Cauliflower is an excellent source of vitamin C, folate, vitamin B6 and pantothenic acid. Lettuce is a rich source of vitamins B1, B2 and C and folate. Mushrooms are an excellent source of vitamin B2, niacin and pantothenic acid. Red bell peppers are an excellent source of vitamin B6. Vitamin B12 is not reported in vegetables. Animal sources include salmon, tuna, cod, lamb, scallops, shrimp and beef.

Vitamin E is a fat-soluble vitamin and functions as the major lipid-soluble antioxidant in cell membranes. It is a free radical scavenger, inhibits lipid peroxidation and has been reported to suppress chemically induced tumours. In addition, vitamin E blocks the in vivo formation of N-nitroso compounds, which have been associated with certain cancers. At least eight different tocopherols and tocotrienols have vitamin E biological activity. The most active form of vitamin E, α-tocopherol, is most widely distributed in nature. Relatively few studies have examined the protective effect of vitamin E in human cancer. In general, the observational studies are most supportive of a protective role of vitamin E in lung, cervical and colorectal cancers. Cancer mortality rates were also found to be inversely associated with blood selenium concentration. Selenium is best known for its presence at the active site of the enzyme glutathione peroxidase, which catalyses the oxidation of hydroperoxides. Selenium may inhibit the development of cancer through other mechanisms including inhibition of cell proliferation and stimulation of the immune system. Selenium and vitamin E have been reported to compensate for the deficiency of each other and to act synergistically to inhibit carcinogenesis. The potential role of other dietary antioxidants (e.g. some flavonoids) is also under investigation (Prior and Cao 2000).

3.2 Major Phytochemicals in Vegetables

Phytochemicals are bioactive plant compounds in vegetables and other plant foods that have been hypothesised to reduce the risk of major chronic diseases (Craig and Beck 1999; Liu 2004). More than 5000 individual dietary phytochemicals have been identified in fruits and vegetables and are grouped into six major classes as phenolics, alkaloids, nitrogen-containing compounds, organosulphur compounds, phytosterols and carotenoids according to their chemical structure and biological activity (Fig. 3.1). However, of the phytochemicals with antioxidant properties, 35% come from carotenoids and 65% come from flavonoids. Vegetable consumption has also been shown to have inverse association with the incidence of many types of cancer, including stomach, colon, breast, lung and prostate cancers. A high-vegetable diet has been associated with lower risk of cardiovascular disease in humans. Low vegetable intake, in unbalanced diets, has been estimated to cause about 31% of ischaemic heart disease and 11% of stroke worldwide. According to the 2007 World Health Report, unbalanced diets with low vegetable intake and low consumption of complex carbohydrates and dietary fibre are estimated to cause some

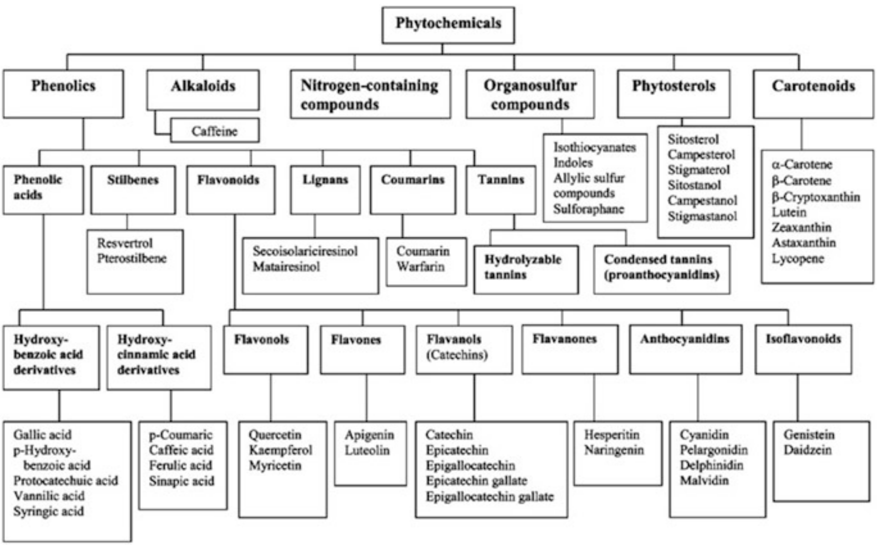


Fig. 3.1 Six major classes of phytochemicals. (Source: Liu 2004)

2.7 million deaths each year and were among the top ten risk factors contributing to mortality.

Each vegetable group contains a unique combination and an amount of these phytonutraceuticals, which distinguishes them from other groups and vegetables within their own group. For example, *Brassica oleracea* (Cruciferae) vegetables (cabbage, broccoli, cauliflower, Brussels sprouts, kale) contain two different kinds of sulphur-containing phytochemicals, viz. glucosinolates and *S*-methylcysteine sulfoxide. These compounds show quite different toxicological effects and appear to possess anticarcinogenic properties. A diet rich in crucifers is likely to protect humans against colon, rectum and thyroid cancers. Crucifer vegetables are also rich in vitamins, with kale was rated as the second highest among 22 vegetables tested. Brussels sprouts and broccoli were also ranked high in their vitamin content containing significant amounts of vitamins C and E and β-carotene. Other antioxidants in crucifers include flavonoids. Broccoli, kale, Brussels sprouts, cabbage and other cruciferous vegetables are rich in folic acid. Inadequate intake of folic acid during pregnancy increases the risks of preterm delivery, low birth weight, foetal growth retardation and neural tube defects—anencephaly (malformed brain) and spina bifida (malformation of the spine).

Tomato and tomato-based products are considered healthy foods because they are low in fat and calories, cholesterol free and a good source of fibre, vitamins A and C, β-carotene, lycopene and potassium. A 100 g tomato can supply about 20–40% of the recommended daily intake of vitamins A and C, respectively. Epidemiological studies indicated that tomato fruit had one of the highest inverse correlations with cancer risk and cardiovascular disease, including stroke. Lycopene, the principal pigment responsible for the characteristic deep-red colour of ripe tomato fruit and tomato products, is a natural antioxidant that can prevent cancer and heart disease. Although lycopene has no provitamin A activity, it does exhibit antioxidant activity almost twice as high as that of β-carotene. Fresh tomato fruit contains about 0.72–20 mg of lycopene per 100 g of fresh weight. Other tomato components that can contribute to health include flavonoids, folic acid and vitamin E. The antioxidant effect of tomato is most probably due to synergism between several compounds and not due to lycopene content alone. All fresh peppers are excellent sources of vitamins C and K, carotenoids and flavonoids. Antioxidant vitamins A and C help to prevent cell damage, cancer and diseases related to ageing, and they support immune function. They also reduce inflammation like that found in arthritis and asthma. Vitamin K promotes proper blood clotting, strengthens bones and helps protect cells from oxidative damage.

Peppers add flavour and colour to many low-calorie dishes. All fresh peppers are excellent source of vitamins C and K, carotenoids and flavonoids. Red peppers are a good source of lycopene, which helps to prevent prostate cancer as well as cancer of the bladder, cervix and pancreas. β-Cryptoxanthin, another carotenoid in red peppers, helps to prevent lung cancer related to smoking. Besides being rich in phytochemicals, peppers provide an appreciable amount of fibre. Fresh chilli hot peppers, red or green, are a rich source of vitamin C. Chillies are also good source of B-complex group of vitamins such as niacin, pyridoxine (vitamin B6), riboflavin and thiamin (vitamin B1). Chilli contains a good amount of minerals like potassium, manganese, iron and magnesium. Potassium is an important component of cell and body fluids that helps in controlling heart rate and blood pressure. The Cucurbitaceae family (e.g. pumpkin, squash, melon, cucumber) is rich in vitamin C, carotenoids and tocopherols. A survey of 350 melon accessions from different horticultural groups of *Cucurbita melo* observed a 50-fold variation in ascorbic acid content, ranging from 0.7 to 35.3 mg/100 g of fresh fruit weight. Ascorbic acid and β-carotene content ranged from 7.0 to 32.0 mg/100 g and 4.7 to 62.2 μg/100 g, respectively, in sweet melons. Bitter gourd (*Momordica charantia*) has anti-diabetic properties because of the presence of triterpenoids and can be used to ameliorate the effects of type 2 diabetes.

Allium vegetables (Alliaceae family) include garlic, onion, leek, chive and Welsh onion, among other vegetables. They are rich in a wide variety of thiosulphides, which have been linked to reducing various chronic diseases. Onions are a rich source of dietary fibres and especially of inulin, a polyfructosan. Apiaceae family (e.g. celery, parsley, carrot) is rich in flavonoids, carotenoids, vitamin C and vitamin E. Celery and parsley for example are among the best vegetable sources for the flavonoid apigenin and vitamin E, and carrots have a unique combination of three flavonoids: kaempferol, quercetin and luteolin. The *Compositae* family (e.g. lettuce, chicory) is rich in conjugated quercetin, flavonoids and tocopherols. The *Cucurbitaceae* family (e.g. pumpkin, squash, melon, cucumber) is rich in vitamin C, carotenoids and tocopherols. The *Chenopodiaceae* family (e.g. spinach, Swiss chard, beet greens) is an excellent source of folate. These vegetables are also among the most oxalate-dense vegetables.

The exact mechanism by which vegetables decrease the risk of disease is complex and largely unknown. Various components of the whole food are likely to contribute to the overall health benefit (Abuajah et al. 2015). Various phytochemicals with antioxidant properties may work directly by quenching free radicals or indirectly by participating in cell signalling pathways sensitive to redox balance (Halliwell and Gutteridge 1999). Nutrients such as potassium contribute to blood pressure regulation. The dietary fibre content and type of different vegetables may also contribute to the overall health benefit, such as improving bowel transit, lowering cholesterol, helping manage blood glucose concentrations and transporting a significant amount of minerals and phytochemicals linked to the fibre matrix through the human gut. Finally, increasing vegetables in the diet may reduce the intake of saturated fats, trans-fats and foods with higher caloric density, all of which may be related to a healthier overall diet. Furthermore, phytochemicals inhibit phase I enzymes, which initiate carcinogenesis, thus reducing the risk of carcinogenesis, and they also induce phase II enzymes, which detoxify and excrete carcinogens, resulting in less DNA damage and preventing carcinogenesis initiation. Also, phytochemicals can reduce the rate of cancer spread by slowing the proliferation of cancer cells. Some phytochemicals have been shown to have an anti-inflammatory function. Inflammation involves the secretion of oxidants and aggregation of platelets, which initiate blood clotting and thereby induce stroke. As a result, certain phytochemicals prevent strokes from occurring by reducing inflammation or inhibiting clot formation.

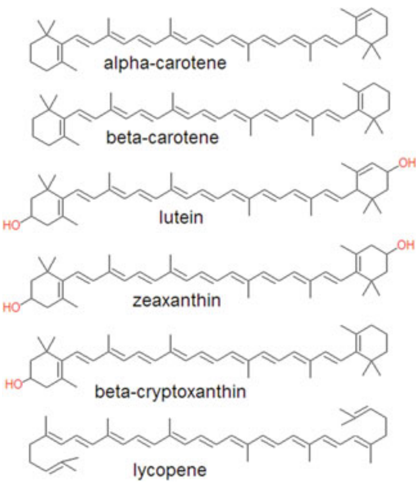
Thousands of phytochemicals have been identified in vegetables, and they are grouped into several classes according to their chemical structure and biological activity.

3.2.1 Carotenoids

Carotenoids are widespread plant pigments that contribute to the yellow, orange and red colours of fruits and vegetables (Fraser and Bramley 2004). Over 600 different carotenoids have been identified to date, and out of these 600 naturally occurring lipophilic pigments, 14 are found in human serum and 6 are commonly found in vegetables. About 50 carotenoids can be converted to vitamin A. It is estimated that approximately 60% of dietary vitamin A comes from plant food sources. Additionally, carotenoids are well known for their antioxidant property, which is associated with a reduction in the risk of several cancers, CVDs, macular degeneration and cataracts, as well as enhancement of the immune system.

The polyene chain is the structural feature of carotenoids that determines the chemicals' reactivity of carotenoids toward free radicals and its antioxidant properties (Fig. 3.2). β-Carotene, which has the highest provitamin A activity, is found mainly in orange-coloured fruits and vegetables and dark-green leafy vegetables, including carrots, pumpkin, sweet potato, apricot, spinach and kale. In addition, β-carotene may protect the skin from ultraviolet (UV) irradiation. Hundreds of studies have shown that people who eat more β-carotene-rich fruits and vegetables have lower risks of cancer or heart disease.

Some specific carotenoids such as lutein and zeaxanthin that are contained in green and yellow leafy vegetables can play an important role in reducing the risk of age-related macular degeneration and cataracts, the most common causes of visual



Carotenes:
- α-carotene
- β-carotene
- lycopene

Xanthophylls:

β-cryptoxanthin
Lutein
Zeaxanthin

Fig. 3.2 Chemical structure of six major carotenoids found in vegetables

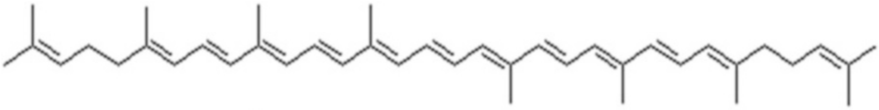


Fig. 3.3 Chemical structure of lycopene

impairment. Lutein and zeaxanthin are the only carotenoids that accumulate in the macula of the human retina, which may contribute to their association with prevention of eye diseases (Havaux et al. 2004).

Lycopene is a red carotenoid found in tomato, watermelon, pink grapefruit and other red fruits, and it has been recognised as the most effective antioxidant in the family of carotenoids. Since lycopene does not contain β-ionone ring structure at the end of the molecule, it cannot be converted to vitamin A. However, it has a higher antioxidant activity as compared to α- and β-carotene because of increased reactivity of lycopene with singlet oxygen and free radicals. Many animal and human studies have shown that lycopene has a protective effect against carcinogens in the liver, brain, colon, breast, cervix and prostate, therefore preventing or delaying certain types of cancer. In addition, lycopene has a preventive effect against coronary heart disease (Fig. 3.3).

3.2.2 Xanthophylls

Lutein and zeaxanthin: These are two very important eye nutrients that may reduce the risk for macular degeneration and cataracts. Lutein, zeaxanthin and meso-zeaxanthin in the macula block blue light from reaching the underlying structures in the retina, thereby reducing the risk of light-induced oxidative damage that could lead to macular degeneration (AMD). Zeaxanthin deficiency results in our eyes getting susceptible to age-related macular degeneration. The compound accumulates in our macula, at the back of our eyes. It protects against blue light, which is particularly damaging as it can oxidise our photoreceptors, which leads to macular degeneration. Too much blue light can damage the light receptors (called cones) in the retina that are responsible for high-resolution central vision and colour perception. The more zeaxanthin in your macula, the more blue light is naturally screened from hitting the back of the eye. In addition to this, lutein and zeaxanthin appear to have important antioxidant functions in the body and guard the body from damaging effects of free radicals. Our body cannot synthesise this pigment, so we must obtain it from dietary sources. University of Queensland has recently identified the orange capsicum as the richest source of the pigment zeaxanthin, which is vital for central vision.

3.2.3 Flavonoids

Flavonoids are a group of phenolic compounds that includes anthocyanins, catechins, flavanones, flavones, isoflavones and flavonols. Anthocyanins are just one of the 6000 different flavonoids (polyphenol). Others include flavanols, flavones, flavanones, flavan-3-ols and isoflavones. To date, more than 635 different anthocyanins have been identified. Anthocyanins possess anti-diabetic, anticancer, anti-inflammatory, antimicrobial and anti-obesity effects, as well as prevent cardiovascular diseases (CVDs). These health benefits are mainly associated with their antioxidant effects. They give vegetables their deep red, purple or blue hues.

The deep red colour of beets and amaranth is due to the presence of betalain pigments. Both betalains and anthocyanins are water-soluble pigments. However, betalains are structurally and chemically unlike anthocyanins and the two have never been found in the same plant. Betalains contain nitrogen whereas anthocyanins do not. Betalains consists of two structural groups such as betacyanins (red violet) and betaxanthins (yellow orange). Betacyanins appear reddish to violet and include betanin, isobetanin, probetanin and neobetanin. Betaxanthins appear yellow to orange and include vulgaxanthin, miraxanthin, portulacaxanthin and indicaxanthin. They exhibit antioxidant and anti-inflammatory properties, which protect human cells from oxidative stress. Animal studies show that these substances lower the amount of inflammation in blood vessels that prevents the formation of clots. Betalain is being commercially used as a natural food dye.

Flavonoids are widely found in berries, citrus fruit, broccoli, cabbage, cucumber, green pepper, etc. The *Apiaceae* family (e.g. celery, parsley, carrot) is rich in flavonoids, carotenoids, vitamin C and vitamin E. Celery and parsley for example are among the best vegetable sources for the flavonoid apigenin and vitamin E, and carrots have a unique combination of three flavonoids: kaempferol, quercetin and luteolin. The *Asteraceae* or *Compositae* family (e.g. lettuce, chicory) is rich in conjugated quercetin, flavonoids and tocopherols. All the legumes (*Fabaceae* or *Leguminosae* family, e.g. bean, pea, soybean, chickpea, lentils) and mature and immature seeds are good sources of dietary fibre and isoflavonoids. Flavonoids have been shown to have a wide range of benefits to human health, such as the ability to prevent cancers, cardiovascular disorders, urinary tract infections (UTIs) and other degenerative diseases. These protective effects of flavonoids against diseases may be associated mainly with their strong antioxidant property, as well as with other biological properties, including action against allergies, inflammation, free radicals, hepatotoxins, platelet aggregation, bacteria, viruses, ulcers and tumours.

The most studied flavonols are kaempferol, quercetin, myricetin and luteolin (Table 3.1). Quercetin is one of the key flavonols, which are the most widespread flavonoids in foods, and is mainly contained in apple skin, red onion and red grape. Quercetin is one of the best antihistamines for relieving allergy symptoms and may

Table 3.1 Flavonol content in some vegetables

Vegetables	Quercetin (mg/100 g fresh weight)	Kaempferol (mg/100 g fresh weight)	Myricetin (mg/100 g fresh weight)	Luteolin (mg/100 g fresh weight)
Lettuce	0.7–3.0	0.2	0.1	0.1
Onion	28.4–48.6	0.2	0.1	0.1
Red pepper	0.1	0.2	0.05	0.7–1.4
Broad bean	2.0	0.2	2.6	0.1
French bean	1.9–18.35	0.56–1.48	–	–

also interact with specific carcinogens in the gastrointestinal tract. Many studies have found an inverse association between quercetin intake and coronary heart disease, which may be attributed to the actions of preventing LDL oxidation, reducing damage to DNA and inhibiting platelet aggregation.

3.2.4 Glucosinolates

Glucosinolates are a group of organosulphur compounds. The hydrolytic products of these compounds are biologically active, particularly the aralkyl and indole products, and have been shown to act as anticarcinogens (Kushad et al. 1999). Cruciferous vegetables such as cabbage, kale, broccoli, cauliflower and Brussels sprout are the main source of glucosinolates in human diet and can occur at levels of up to 1% (w/w) in specific tissues of certain plant species. They constitute ~0.05% to 0.1% of the fresh wt. of broccoli (~0.05–1.0 g/kg). Indoles, which are found in cabbage, broccoli and other cruciferous vegetables, are known to have anticarcinogenic properties, as well as a detoxification ability (Li and Zhang 2013). Indole-3-carbinol, one of the indole derivatives, is an inhibitor of chemically induced cancer, mostly because it can boost carcinogen metabolism capacity. In addition, indole-3-carbinol can activate cytochrome P450 enzymes, which have been shown to metabolise oestrogen, and can therefore markedly reduce breast and uterine cancers.

3.2.5 Isothiocyanates

Isothiocyanates are widely distributed in cruciferous vegetables, such as watercress, broccoli and radish. It has been reported that isothiocyanates can activate phase II detoxification enzymes and suppress phase I cancer-promoting enzymes, actions that may contribute to the inhibition of tumorigenesis. One study has shown that watercress consumption accelerates excretion of a pulmonary carcinogen that is one of the causes of lung cancer in smokers. In addition to reducing the risk of lung cancer, isothiocyanates have also been shown to have a preventive effect against tumours in other organs, including the mammary gland, liver, bladder, oesophagus, pancreas and colon.

With the exception of glucosinolates and thiosulphides, which are unique to the crucifers and alliums, the phytochemical content of a number of other vegetables consists primarily of vitamin C, fibre, selenium, folate and polyphenolics (carotenoids and flavonoids). The main difference is that each vegetable group contains a unique combination and an amount of these phytochemicals, which distinguishes them from other groups and vegetables within their own group.

3.2.6 Folic Acid (Vitamin B9)

Folic acid (FA) is a water-soluble vitamin B9, also called folate. Humans cannot synthesise folates de novo; therefore, folate has to be supplied through the diet. Women of childbearing age and pregnant women have a special need for folate. Folate deficiency is accelerated by alcohol consumption. Those with liver disease, or who are receiving kidney dialysis treatment, may benefit from a folic acid supplement. People taking drugs/medications which may interfere with the action of folate (dilantin phenytoin and primidone) (epilepsy) metformin (type 2 diabetes) and low-dose methotrexate (anti-allergic diseases—asthma, psoriasis, rheumatoid arthritis) (Fig. 3.4).

Good sources of folic acid include spinach, broccoli, kale, Brussels sprouts, cabbage, beans and other legume vegetables. Inadequate intake of folic acid during pregnancy increases the risks of preterm delivery, low birth weight, foetal growth retardation and neural tube defects—anencephaly (malformed brain) and spina bifida (malformation of the spine) (Fig. 3.5).

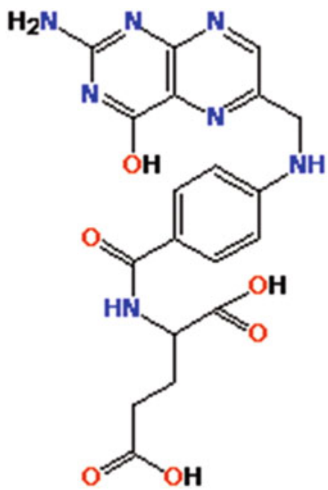


Fig. 3.4 Chemical structure of folate

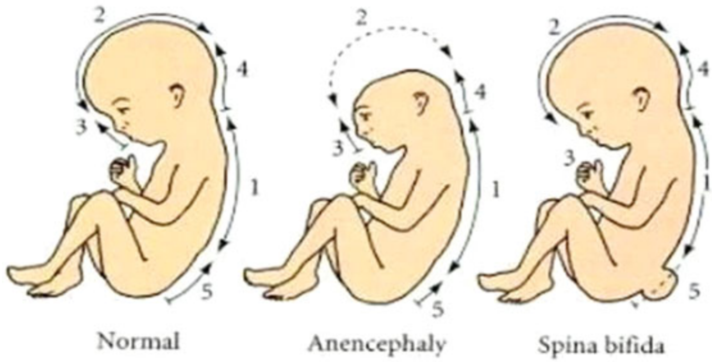


Fig. 3.5 Normal foetus and foetuses with neural tube defects

3.3 Associations Between the Intake of Vegetables and the Risk of Several Chronic Diseases

The importance of vegetables as sources of nutrients and non-nutritive food constituents is generally accepted; however, there are still uncertainties regarding their relevance for the prevention of diseases. For hypertension, CHD and stroke, there is *convincing evidence* that increasing consumption of vegetables and fruits reduces the risk of disease. There is *probable evidence* that the overall risk of cancer is inversely associated with the consumption of vegetables. In addition, there is *possible evidence* that a diet with increased consumption of vegetables may prevent body weight gain. As overweight is the most important risk factor for type 2 diabetes mellitus, an increased consumption of vegetables and fruits might indirectly reduce the incidence of type 2 diabetes mellitus. Furthermore, the data indicates that an increased consumption of vegetables also reduces the risk of certain eye diseases, RA and osteoporosis. Likewise, the present data also indicates that an increase in vegetable consumption may contribute to the prevention of the lung diseases, asthma and COPD.

3.3.1 Vegetables and Obesity

The prevalence of pre-obesity and obesity has been rising in recent decades. Overweight occurs if energy intake is higher than energy expenditure. Compared with many other foods, the volume of vegetables in relation to the energy content is larger. Due to the favourable volume-to-energy ratio of vegetables, satiety signals can emerge without consuming a large amount of energy. The extent is not known to which individual bioactive constituents of vegetables and fruits such as dietary fibre are involved in the regulation of hunger and saturation and hence body weight. In an intervention study, it was shown that an increase in vegetable intake enhances weight loss; however, another intervention study with 1510 women with breast cancer did not observe weight loss with such an intervention over 4 years. It can be concluded from the prospective and the intervention studies that there is *possible* evidence that an increase in the consumption of vegetables and fruits contributes to *weight stability* (i.e. no weight increase occurs). There is also *probable* evidence that an increase in vegetable consumption alone does *not* result in *weight loss*. There is *probable* evidence that an increase in the consumption of vegetables leads to weight reduction, if this replaces foods rich in fat or energy.

3.3.2 Vegetables and Type 2 Diabetes Mellitus

Type 2 diabetes mellitus is one of the most common and most expensive chronic diseases. According to the International Diabetes Federation, the diabetes prevalence in the 20- to 79-year-olds was 6.4% for women with large regional differences (e.g. 3.8% in Africa, 6.9% in Europe and 10.2% in North America). Due to ageing of populations, this prevalence is expected to increase to 7.7% by the year 2030 with an expected 237 million affected individuals. These estimates include millions of undetected cases, because at the beginning, the disease often is free of symptoms and is only diagnosed years later, but does not include the rise of prevalence due to changes in other major risk factors beyond age, like the rise of obesity prevalence rates and adoption of westernised diet and lifestyle habits in many parts of the world. Type 2 diabetes mellitus develops due to a complex interaction between genetic predisposition and lifestyle. The actual manifestation of the disease is preceded by a phase of impaired glucose regulation, in which the cardiovascular risk is already increased. Particularly important among the lifestyle factors that promote or accelerate the manifestation of type 2 diabetes mellitus are bad nutritional habits and a lack of physical activity. However, the most important risk factor for the development of type 2 diabetes mellitus is truncal obesity, which also is the result of an unfavourable lifestyle including overeating and a lack of physical activity. Several studies and their meta-analysis indicate a lack of an association between the consumption of vegetables and the risk of diabetes. Because of this, there is *probable* evidence that the risk of developing type 2 diabetes mellitus is not influenced by the consumption of vegetables. However, vegetables and fruits indirectly influence the prevention of type 2 diabetes mellitus, as consumption thereof might lower the risk of weight gain in adults.

3.3.3 Vegetables and Hypertension

Hypertension is one of the most relevant clinical findings for public health policy, with a global prevalence of 26% in the adult population. Further, 29% were projected to have this condition by 2025. Due to the increased risks of stroke and CHD, and also of renal cancer associated with hypertension, lifelong medication is usually required. It could be shown that even a slight reduction in the mean blood pressure in the population strongly reduces the incidence of cardiovascular diseases. The *American Heart, Lung and Blood Institute* has stated in 2003 that the measures for the prevention of hypertension include a health-promoting lifestyle, which in addition to weight reduction (at existing overweight) comprise the adherence to the DASH diet, limitation of sodium and alcohol intake as well as increased physical activity. The *ESH–ESC Task Force on the Management of Arterial Hypertension* of the European Society of Hypertension states the increase in the consumption of vegetables and fruits as one of the lifestyle measures that can lower blood pressure in individuals with only a few risk factors for cardiovascular diseases and slightly increased blood pressure (Southon 2000). In vegetarians, there is often a lower blood pressure observed than in the total population, and a reduction in the blood pressure has been seen after changing from a normal to a vegetarian diet. In cohort studies, there was an inverse relation between the consumption of vegetables and new cases of hypertension. Another analysis of the *Nurses' Health Study* (NHS) I and II and the *Health Professionals Follow-up Study* (HPFS) after 14 years of follow-up with flavonoid intake showed a risk reduction in hypertension with increasing intake of anthocyanins.

3.3.4 Vegetables and Coronary Heart Disease (CHD)

Coronary heart disease (CHD) is the most important manifestation of arteriosclerosis in humans and belongs to the large group of cardiovascular diseases. CHD is still the single largest cause of premature death in the world. Ischaemic heart disease has been estimated to account for 12% of all deaths worldwide in 2004. In 2008, 17 million deaths worldwide were due to cardiovascular diseases, accounting for 48% of non-communicable disease deaths. While CHD death rates have declined in many parts of the industrialised world, death rates are increasing in most developing countries. In addition to age and gender, modifiable risk factors are important, especially lifestyle factors like smoking and a lack of physical activity and the medical diagnoses of hypertension, diabetes mellitus and obesity. Many cohort studies have shown a protective association between the consumption of vegetables and the risk of CHD. In addition, there are intervention studies that prove a beneficial influence of vegetables and fruits on metabolic pathways that are associated with the risk of CHD. It has been shown that the higher the average daily intake of fruits and vegetables, the lower the chances of developing cardiovascular disease. It has been reported that individuals with the lowest category of fruit and vegetable intake (less than 1.5 servings a day), compared to those who averaged 8 or more servings a day, were 30% less likely to have had a heart attack or stroke (Hung et al. 2004). Researchers have also reported that individuals who ate more than 5 servings of fruits and vegetables per day had roughly a 20% lower risk of coronary heart disease (He et al. 2007) and stroke (He et al. 2006) compared with individuals who ate less than 3 servings per day.

3.3.5 Vegetables and Cancer

Cancer is one of the most important chronic diseases. The occurrence of cancer as a whole is increasing with age, and the pathogenesis often takes several decades. The disease is characterised by chromosomal changes that can be induced due to different reasons. In addition to age, the most important risk factors include tobacco smoking, consumption of alcohol, overweight, hormonal factors, physical activity and food intake. Epidemiologic evidence of a protective role for fruits and vegetables in cancer prevention is substantial (Van Duyn and Pivonka 2000). A summary published in 1992 of the results of epidemiological studies, mostly case–control studies, on the association between consumption of vegetables and occurrence of cancer showed high consistency regarding an inverse risk relation (Waladkhani and Clemens 1998). In the report of WCRF experts published in 1997, vegetables were rated among the most important cancer-preventive factors with a calculated prevention potential of 23%. The analysis of the NIH–AARP showed a significantly reduced risk at high vegetable intake in men, but not in women. In the *EPIC study*, a lowered risk of cancer was observed with higher intake of vegetables. Studies suggest that increased consumption of tomato-based products (especially cooked tomato products) and other lycopene-containing foods may reduce the occurrence of prostate cancer. (Wiseman 2008). Lycopene is one of several carotenoids (compounds that the body can turn into vitamin A) found in brightly coloured fruits and vegetables, and research suggests that foods containing carotenoids may protect against lung, mouth and throat cancer (Wiseman 2008). A report by the World Cancer Research Fund and the American Institute for Cancer Research suggests that non-starchy vegetables such as lettuce and other leafy greens, broccoli, bok choy, cabbage as well as garlic and onions ‘probably’ protect against several types of cancers, including those of the mouth, throat, voice box, oesophagus and stomach (Wiseman 2008). But more research is needed to understand the exact relationship between fruits and vegetables, carotenoids and cancer (Steinmetz and Potter 1996).

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Nutritive Vegetable Crop Germplasm for Future Food Security

4

Veena Gupta and Chithra Devi Pandey

Abstract

Vegetables are the key component of balanced human diet and also the main drivers in achieving global nutritional security by providing nutrient, vitamins and minerals. Malnutrition, comprising undernutrition, micronutrient deficiency and overnutrition, is more widespread than hunger per se and affects most nations around the globe. In this context, fruit, vegetables and nuts are increasingly moving into the focus of the nutrition community, which mainly revolves around the cultivated species. These vegetables are well represented in gene banks around the globe, but the case is entirely opposite when it comes to local/traditional vegetables consumed by the tribals and local communities. Collection and conservation of this wild/semi-domesticated local germplasm of vegetables need concentrated efforts in hotspots of vegetable diversity in Asia, particularly in India, before it is being replaced by modern varieties. This will enhance the availability of diverse germplasm to vegetable breeders who need a wide diversity of genetic resources, predominantly farmers' varieties, landraces and crop wild relatives. ICAR-National Bureau of Plant Genetic Resources (ICAR-NBPGR) has been entrusted to collect, conserve and characterize the genetic resources of all agri-horticultural crops including vegetables. ICAR-NBPGR has ten regional stations in different agro-climatic zones of the country supported by 59 crop/crop group-based National Active Germplasm Sites (NAGS). These NAGS are entrusted with the responsibility of multiplication, evaluation, conservation of active collections and their distribution to users both at national and international levels.

V. Gupta (✉) · C. D. Pandey
Division of Germplasm Conservation, ICAR-NBPGR, New Delhi, India
e-mail: veena.gupta@icar.gov.in

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Conservation · Vegetable · Germplasm · Nutrition · Gene bank · Germplasm registration

4.1 Introduction

Nutrition is both a quantity and a quality issue, and vegetables ensure an adequate intake of most vitamins and nutrients, dietary fibres and phytochemicals, which can bring a much-needed measure of balance back to diets contributing to solving many of these nutrition problems. Each vegetable group contains a unique combination and amount of these phyto-nutraceuticals, which distinguishes them from other groups and vegetables within their own group. Many of these phyto-nutraceuticals are strong antioxidants and are thought to reduce the risk of chronic disease by protecting against free radical damage. The diverse agro-climatic conditions of India allow growing more than 60 cultivated and about 30 lesser known vegetable crops (Jena et al. 2018). Vegetable crops are grown throughout the country; several of them have wider adaptability to diverse cultural conditions. However, the temperate vegetables with more specific requirement are grown mainly in the Himalayan ranges and to some extent in the higher ranges of the Western and Eastern Ghats. The seat of diversification of many of the important vegetables, especially the cucurbits and solanaceous vegetables (especially chilli), has been in peninsular India; for tomato, onions, garlic and okra in the north-western and central parts; for beans in the northern hills; and for underutilized leguminous vegetables like sword bean and winged bean in the north-eastern parts. This has also been influenced by consumers' preferences for taste, marketability and other socio-economic factors.

4.2 National Scenario

A world survey has shown that 402 vegetables are cultivated throughout the globe belonging to 69 families and 230 genera, of which 53% are leafy vegetables, 15% are vegetable fruits and 17% comprise the underground vegetables. In India, a variety of vegetables in different categories are grown and consumed. The most common leafy vegetables in northern plains are *Spinacia oleracea* and *Chenopodium album*, whereas *Brassica oleracea* var. *rugosa* (elephant ear brassica, pahadi sarson) and *Portulaca oleracea* (purslane) are favourite among diets of the local communities in Himalayan region; in southern and western plains of Bihar, Odisha and Bengal, leafy-type amaranths, *Basella rubra* and *Ipomoea aquatica*, are consumed. Native tribes use more than 145 roots and tubers and 521 species as leafy vegetables as green (Pandey et al. 2019). Traditional vegetables are an important asset for meeting this challenge as many have high nutritional value, low water requirements, adaption to poor-quality soils and good resistance to pest and disease, but lack of knowledge and research generally challenges the promotion and use. The vegetable crops occupy 10.43 million ha, producing 187.47 million metric tons per annum (NHB Database, 2019). More than 50 vegetables are commercially cultivated in India besides many grown in kitchen gardens/backyard gardens in semi-domesticated form. An equal number of vegetables are consumed directly from the wild habitat. So far, research has confined to 30 vegetables with tomato, brinjal, chilli, okra, cauliflower, melons, onion, peas, etc. as major crops. Around 25 potential crops required research and development attention. The vegetable platter of India based on plant parts used comprises 74 as leafy and salad; 39 as fruit vegetables; 8 as flowers and buds; 32 as podded vegetables; 25 as bulbs and stem; and 45 as root and tuberous vegetables.

4.3 Vegetable Genetic Resources: Diversity Distribution in India

India represents a large diversity both generic and species for vegetable genetic resources. The indigenous diversity includes eggplant, different types of gourds, round melon and snap melon in melon group, chenopods, amaranths in leafy vegetables, and tuberous crops like yams, taro, and ginger. An equal number of exotic vegetables are also part of our platter as tomato, peas, beans, pepper, alliums, etc. India is a primary centre of diversity for vegetables like brinjal, cucumber, and ridged and sponge gourd whereas secondary centre of diversity for vegetables like cowpea, okra, chilli and watermelon. Many vegetables are commercially cultivated, while an equal number of vegetables are consumed in wild or semi-domesticated forms (Table 4.1). Due to the varied climatic conditions of Indian subcontinent, vegetable crops are widely distributed across the country. North-eastern region is rich in diversity of *Solanum* species, whereas Western Ghats and South-Eastern Ghats possess diversity in yams while Western Himalayas are rich in chives, leeks and other wild *Allium* spp. North-eastern region is rich in underutilized solanaceous vegetables, leafy vegetables, less known legume vegetables (winged bean, jack bean, sword bean) and cucurbits (cho-cho and meetha karela). The northern Gangetic plains exhibit variability in cucurbits, while the central plateau has more diversity in cucurbits like melon, bitter gourd, pointed gourd and ridged gourd. Western and eastern peninsular regions are rich in diversity of crops like snake gourd, sponge gourd, ridged gourd and *Moringa*.

4.4 Collection of Vegetable Germplasm

Systematic plant germplasm exploration and collection activity started way back in 1946, and the activities were further strengthened in 1976 when ICAR-NBPGR was formed. Till 1999, crop-specific and region-specific/multi-crop exploration activities were undertaken involving regional stations and base centres, but later on, there was a paradigm shift into crop-specific and trait-specific germplasm collection from diversity-rich areas. Up to 2019, a total of 64,056 germplasm accessions of various

Table 4.1 Examples of cultivated and semi-domesticated vegetables in India

Major cultivated vegetables	Few wild/semi-domesticated vegetables
Abelmoschus esculentus (okra), *Allium cepa* (onion), *A. sativum* (garlic), *Amaranthus* spp. (Amaranthus), *Amorphophallus paeoniifolius* (elephant foot yam), *Benincasa hispida* (ash gourd), *Brassica* spp. (leafy brassicae), *Capsicum* spp. (chilli), *Citrullus lanatus* (watermelon), *Coccinia grandis* (ivy gourd), *Colocasia* spp. and *Alocasia* spp. (taros), *Cucumis melo* (melon), *C. sativus* (cucumber), *Cucurbita moschata* (pumpkin), *Dioscorea alata*, *D. deltoidea, D. esculenta* (yams), *Ipomoea batatas* (sweet potato), *Lagenaria siceraria* (bottle gourd), *Luffa acutangula* (ridged gourd), *L. aegyptiaca* (sponge gourd), *Lycopersicon esculentum* (tomato), *Momordica charantia* (bitter gourd), *Phaseolus vulgaris* (French bean), *Pisum sativum* (pea), *Praecitrullus vulgaris* (*Benincasa fistulosa*), *Citrullus vulgaris* var. *fistulosus, Sechium edule* (cho-cho), *Solanum melongena* (brinjal), *S. tuberosum* (potato), *Trichosanthes dioica* (pointed gourd), *T. anguina* (snake gourd), *Vigna unguiculata* (cowpea)	*Abelmoschus angulosus, A. moschatus, A. manihot* and *A. ficulneus*; *Cucumis hardwickii* and *C. trigonus*; *Luffa echinata* and *L. graveolens*; *Solanum indicum* and *S. lasiocarpum*; *Moghania vestita*, *Momordica dioica*, *M. cochinchinensis, M. macrophylla* and *M. subangulata*; *Trichosanthes cucumerina, T. dioica, T. khasiana, T. ovata, T. truncate, T. cuspidate, T. anamalaiensis, T. bracteata, T. perrottetiana, T. villosa* and *T. multiloba; Cucumis setosus, C. hystrix* and *C. trigonus; Amorphophallus campanulatus; Luffa graveolens; Colocasia antiquorum*

vegetables have been collected. Important cultivated vegetable germplasm (58,250) and wild relatives/wild vegetable resources (5806) were assembled from different regions of the country (Pandey et al. 2019). It included major cultivated crop diversity in cucurbitaceous vegetables (16,750), solanaceous vegetables (14,646), root/tuberous vegetables (8298), bulbous vegetables (4769), brassica/cole crops (1776), leafy vegetables (2084), leguminous vegetables (5435), okra (4235) and tree crops (257).

4.5 Nutritive Primary and Secondary Introductions in Some Vegetable Crops

One of the exotic fruit vegetables introduced is watermelon. Two varieties include Asahi Yamato (e.g., Japan), with fruit medium in size, 5–8 kg each, flesh deep pink, mid-season type, and Sugar Baby (e.g., USA), with fruits round, fine textured, attractive in dull-green skin; flesh uniform deep red, very sweet, 10–12% TSS, with average fruit weight 3–5 kg. Similarly, in tomato, Karboreta variety is introduced with resistance to tobacco mosaic virus (TMV) and cracking, rich in ß-carotene (3–4 mg/100 g) and ascorbic acid (20–30 mg/100 g). In turnip, Pusa Kanchan, a hybrid (Local Red Round × Golden Ball), has been developed which possesses leaves with high ascorbic acid content. In carrot, Pusa Yamdagini

(EC9981 × Nantes) is a high-yielding variety, with orange-coloured core, rich in carotene (developed at IARI, Katrain, HP).

4.6 Conservation of Vegetable Germplasm at National Gene Bank

The National Gene Bank (NGB) at ICAR-NBPGR has three components for the conservation of base collections for future needs. These are (1) seed gene bank to conserve the genetic resources of orthodox seed crops at −18 °C, (2) *in vitro* gene bank to conserve the genetic resources of vegetatively propagated crops in the form of tissue culture at 4–25 °C, and (3) cryobank to conserve the genetic resources of recalcitrant seed (difficult to store) and clonally propagated crops at −156 °C to −196 °C (in liquid nitrogen). The National Gene Bank network is well supported by field gene bank repositories and conservation of active collections at ICAR-NBPGR regional stations and National Active Germplasm Sites at crop-based institutes (Fig. 4.1).

Presently in the NGB, ~0.45 million accessions belonging to 1995 species are conserved as base collections at NGB. The vegetable genetic resources are 26,230 (March 2021) accessions belonging to 76 crops comprising 21,765 indigenous collections and 4465 exotic collections (Table 4.2).

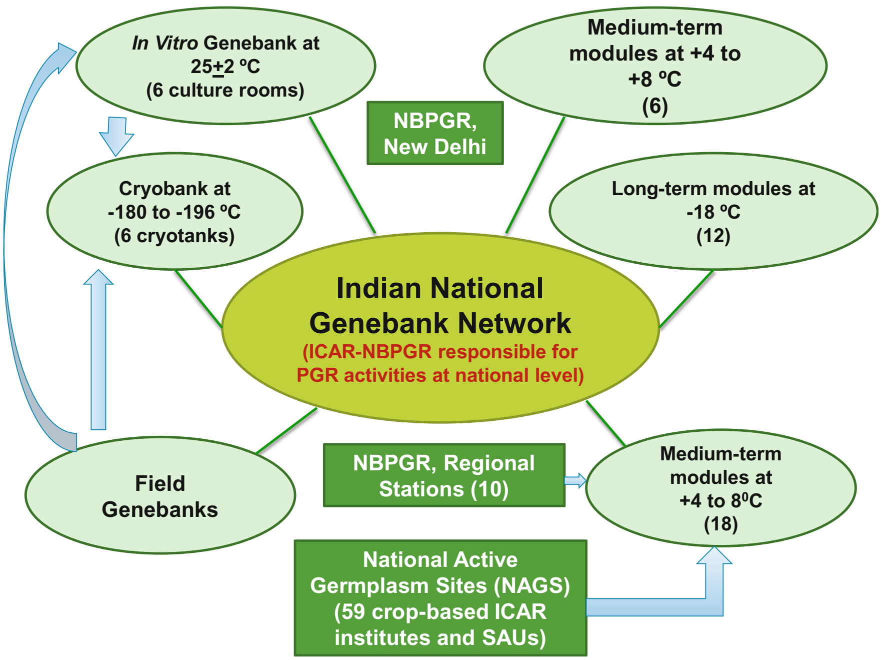

Fig. 4.1 Indian National Gene Bank Network

Table 4.2 Status of vegetable genetic resources at National Gene Bank (March 2021)

Crop name	Botanical name	Acc. no.
Okra	*Abelmoschus esculentus*	3057
Wild okra Musk mallow	*Abelmoschus betulifolius, A. crinitus, A. ficulneus, A. manihot* spp. *manihot, A. manihot* var. *pungens, A. manihot* var. *tetraphyllus, A. moschatus* var. *tuberosus, A. pungens, A. tetraphyllus, A. tuberculatus, Abelmoschus* sp. *A. manihot, A. moschatus, A. angulosus, A. angulosus* var. *grandiflorus, A. caillei, A. lampus, A. tetraphyllus* var. *pungens, A. mizonagensis* sp. *nova, A. palianus, A. tetraphyllus* var. *nova* *Hibiscus esculentus. A. moschatus. A. caillei*	921
Onion	*Allium cepa*	1016
Wild onion Onion (ornamental) Chinese chives Leek, garlic	*Allium altaicum, A. auriculatum, A. clarkei, A. stracheyi, Allium* sp., *A. fistulosum, A. griffithianum, A. humile, A. wallichii, A. oschaninii, A. albidum, A. pskemense, A. ramosum, A. tuberosum, A. ampeloprasum, A. porrum, A. sativum, A. senescens, A. przewalskianum, A. ascalonicum, Allium carolinianum*	137
Ash gourd	*Benincasa hispida*	284
Cabbage Chinese cabbage Chinese kale Collard green	*Brassica oleracea, B. oleracea* var. *capitata, B. pekinensis, B. oleracea* var. *botrytis, B. oleracea* var. *chinensis, B. chinensis, B. chinensis* var. *pekinensis, B. rapa* var. *chinensis, B. oleracea* var. *alboglabra, B. oleracea* var. *acephala*	612
Knolkhol	*Brassica caulorapa, B. oleracea* var. *caulorapa*	9
Turnip Broccoli	*Brassica campestris, B. campestris L.* var. *rapa, B. campestris* var. *rapifera, B. rapa, B. rapa* var. *rapa, B. oleracea* var. *italica plenck*	1969
Beetroot (Chukandar)	*Beta vulgaris, B. vulgaris* var. *bengalensis*	48
Chilli Sweet pepper	*Capsicum annuum, C. baccatum, C. chinense, C. frutescens, C. annuum* var. *annuum, C. annuum* var. *grossum* *Capsicum* sp.	5092 12
Musk melon	*Cucumis melo, Cucumis melo* var. *reticulatus*	859
Wild Cucumis Cucumber Wild cucumber Long melon, snap melon Pumpkin	*Cucumis melo* var. *conomon, C. trigonus, C. callosus, C. leispermus, Mukia maderaspatana, Mukia maderaspatana, C. hardwickii, C. sagittatus, C. sativus, C. sativus* var. *hardwickii, C. sativus* var. *hardwickii x C. sativus* var. *sativus, C. sativus x hardwickii, Cucumis* sp., *C. prophetarum, C. rati, Cyclanthera pedata, Cucumis melo* var. *utilissimus, C. hardwickii, C. melo* var. *agrestis, C. utilissimus, C. melo* subsp. *Melo, C. melo* var. *momordica, C. hystrix, Cucurbita moschata, C. javanicus, C. leiospermus, C. maderaspatanus, C. metuliferus, C. silentvalleyi, C. setosus, C. dipsaceus Cucumis melo* var. *flexuosus* *C. melo* var. *inodorus, Cucumis muriculatus*	250 775 789

(continued)

Table 4.2 (continued)

Crop name	Botanical name	Acc. no.
Cushaw, pumpkin, winter squash	*Cucurbita* sp., *C. argyrosperma, C. maxima, Praecitrullus fistulosus, Cucurbita pepo*	155
Watermelon	*Citrullus lanatus, Citrullus lanatus* var. *citroides, Citrullus lanatus* var. *lanatus, Citrullus* sp., *Cucumis vulgaris*	318
Round gourd, colocynth	*Citrullus vulgaris* var. *citroides, Citrullus colocynthis*	148
Ivy gourd	*Coccinia grandis, Coccinia indica*	38
Carrot	*Daucus carota, D. carota* var. *sativa*	126
Tomato	*Solanum habrochaites, S. lycopersicum, S. lycopersicum* var. *cerasiforme, S.* sp.	2681
Wild tomato Tamarillo/tree tomato	*Solanum peruvianum, S. pimpinellifolium* *Cyphomandra betacea, Solanum betaceum*	87 5
Sponge gourd	*Luffa aegyptiaca, L. cylindrica, L. graveolens*	463
Ridge gourd Luffa	*Luffa acutangula, L. acutangula* var. *amara, L. hermaphrodita, L. echinata, L. pentandra, L. tuberose. Luffa hermaphrodita*	368
Bottle gourd	*Lagenaria siceraria, L. vulgaris, L.* sp. *Lagenaria sphaerica*	801
Bitter gourd, sweet gourd, teasel gourd, balsam apple	*Momordica charantia, M. charantia* var. *muricata, M. sahyadrica, M. tuberosa, M.* sp., *M. cochinchinensis, M. dioica, Momordica subangulata* ssp. *renigera, M. balsamina*	628
Radish	*Raphanus caudatus, R. sativus*	353
Brinjal	*Solanum melongena*	4094
Wild brinjal Solanum Wild solanum Nightshades Indian nightshades False Jerusalem cherry	*Solanum aethiopicum, S. americanum, S. gilo, S. macrocarpum, S. melongena* var. *incanum, S. muricatum, S. verbascifolium, S. viarum, S. melongena* var. *incanum, S. hispidum, S. incanum, S. melongena* var. *insanum, S. torvum, S. vagum, S. violaceum, S. albicans, S. anguivi, S. laciniatum, S. trilobatum, S. pimpinellifolium, S. pubescens, S. seaforthianum, S. setosissimum, S. virginianum, S. xanthocarpum, S. aculeatissimum, S. aviculare, S. giganteum, S indicum, S. khasianum, S. nigrum, S. sisymbriifolium, S. surattense, S. lasiocarpum, S. pseudocapsicum, S. virginianum, S. spirale, S. exarmatum. Solanum villosum. S. kurzii*	1165
Snake gourd Trichosanthes Wild snake gourd Bull snake gourd Pointed gourd	*Trichosanthes anguina, T. cucumerina, T. palmata, T. wallichiana, T. bracteata, T. cuspidata, T. nervifolia, Trichosanthes* sp., *T. lepiniana, T. lobata, T. tricuspidata, T. dioica, Trichosanthes cucumeroides* var. *dicoelosperma. T. cucumerina T. khasiana. T. majuscule. Trichosanthes quinquangulata, Trichosanthes tricuspidata*	360

(continued)

Table 4.2 (continued)

Crop name	Botanical name	Acc. no.
Spinach Indian spinach	*Spinacia oleracea, Tetragonia expansa, Spinacia* sp., *Basella alba*	206
Lettuce Elephant foot yam Kanjilal/Minangmose	*Lactuca sativa, Tetragonia expansa, Amorphophallus bulbifera, Gymnocladus assamicus*	28

4.7 Few Nutritive Trait-Specific Vegetables Conserved at NGB

Chenopodium, commonly called as bathua, is an important crop for food security, nutrition and poverty eradication in compliance of achieving Millennium Development Goals (UN). It has a high potential both for its nutritional benefits and for its agricultural versatility to contribute to food security in various regions of the planet, especially in countries which are limited in food production or where the population has no access to protein sources. The germplasm conserved at NGB includes high-protein germplasm as IC0415405 (17.7%), IC0611818 (17.6%) and IC0617316 (17.1%); high starch content as IC0258332 (49.6%), IC0415405 (47.8%) and IC0617316 (49.8%); and high dietary fibre content as IC0258332 (12.8%), IC0415405 (12.7%) and IC0107263 (12.6%).

Solanum gilo (syn *Solanum aethiopicum* L) is a less known cultivated introduced vegetable collected and conserved from NEH region. They are reservoirs of minerals, vitamins, carbohydrates, proteins and antioxidants and are considered as a risk aversion crop and a resilient crop towards climate change. A total of five accessions are conserved in the NGB.

Moringa oleifera, commonly called as drumstick, is native to northern India, but a greater diversity is observed in southern India where it is mainly consumed. Nowadays, it is more popular as a nutraceutical food because of its various values. The gene bank conserves 46 germplasm lines. The leaves have 7 times more vitamin C than oranges and 15 times more potassium than bananas. It also has calcium, protein, iron and amino acids.

Sauropus androgynus, commonly called as 'insulin plant', is a wild edible fruit from Arunachal Pradesh, also called multivitamin plant (Fig. 4.2). It is popular as leafy vegetables in South Asia and Southeast Asia. The more the leaves mature, the higher the nutrient content of the leaves, which includes provitamin A, carotenoids, vitamins B and C, protein and minerals.

Fig. 4.2 Fruits of *Sauropus androgynus* 'insulin plant' from Arunachal Pradesh

4.8 Registered Germplasm of Vegetable Crops Conserved in National Gene Bank

Indian Council of Agricultural Research (ICAR) has established a mechanism to register the trait-specific germplasm through ICAR-NBPGR in 1996 (Singh 2006; Tyagi and Kak 2012) to facilitate the flow of germplasm among the scientists working in crop improvement programme, and NBPGR is entrusted with the responsibility for registration of germplasm and is an initiative that provides soft protection to the germplasm having unique traits (Fig. 4.3). Two accessions of *Amaranthus tricolor* are registered under this mechanism for the traits such as thick stem type (Dantu soppu: IC395324) and resistance to white rust (IC395327): *Chenopodium album* (brown seeded: IC258253), *Spinacia oleracea* (terminal flower, thick leaf, big seed mutant of IC565527) and fenugreek (*Trigonella foenum-graecum*: light-green narrow leaves, downy mildew resistant, quick germination, fast initial growth, long pod, bold seed with green tan seed coat colour (IC296791) and tall, erect plant type with multi-branched habit, whitish green stem, dark-green narrow leaves, powdery mildew resistant and downy mildew tolerant (IC296792)) are conserved in NGB. The details of the traits of registered germplasm may be obtained from NBPGR website http://www.nbpgr.ernet.in/IRCG%20Search/index.htm. The registered germplasm is available in public domain, and it is obligatory on the part of the developer to maintain, multiply and supply the registered germplasm to the bona fide users (Tables 4.3 and 4.4).

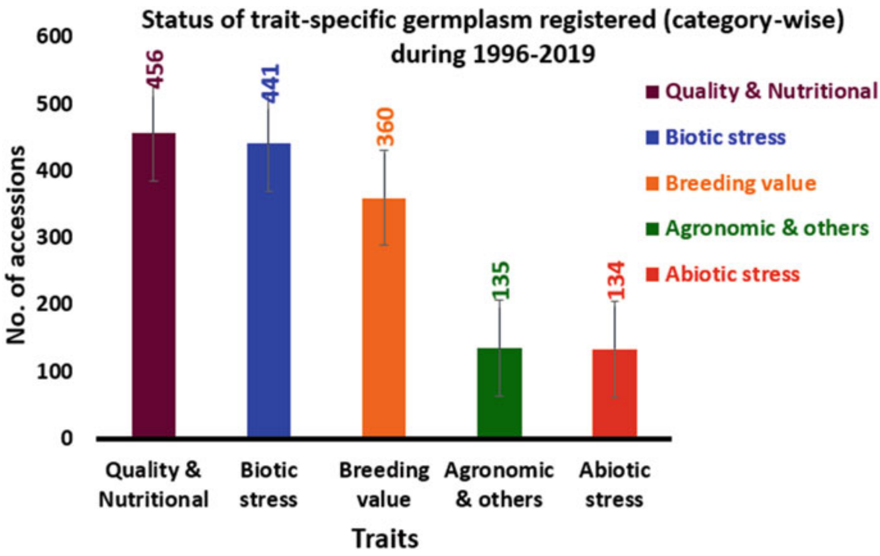

Fig. 4.3 Trait-specific germplasm registered and conserved at NGB, ICAR-NBPGR

Table 4.3 Few trait-specific vegetable germplasms conserved at NGB

Crop name	IC number	Nutritional value
Cucumis melo	IC0265201, IC0599709	High yield and rich in minerals High levels of antioxidants
Daucus carota	IC0593950, IC0596514	High TSS and beta-carotene content (15.14 mg/g), rich in vitamin A content High beta-carotene and sugar
Lactuca sativa	IC0628852	Rich in Fe and calcium
Luffa acutangula	IC0632316	Rich in phenols, flavonoids, antioxidant activity and minerals like phosphorus, calcium and zinc
Basella alba	IC0598152	Rich in Fe and Ca, ascorbic acid and carotenoids
Momordica charantia and M. dioica	IC0353820	Fruits have high nutritive and medicinal value
Cucumber	IC420405 IC257296	High carotenoid content and orange flesh colour Two female flowers per node, earliness and small fruit
Moringa oleifera	IC631054	Rich in glucosinolate content

Table 4.4 National active germplasm sites' network at National Gene Bank

S. no.	Crop(s)	Name of crop-based institute
1.	Cotton	ICAR-Central Institute for Cotton Research (CICR), Post Bag No. 2, Shankar Nagar, Nagpur-440 010, Maharashtra
		All India Coordinated Cotton Improvement Project, Indian Council of Agricultural Research, ICAR-Central Institute for Cotton Research, Regional Station, Lawley Road, Coimbatore-641 003, Tamil Nadu
2.	Crops of North East	ICAR Research Complex for NEH Region, Umroi Road, Umiam-793 103, Meghalaya
3.	Chickpea/pigeon pea/other pulses	All India Coordinated Research Project on Chickpea/pigeon pea/MuLLARP, ICAR-Indian Institute of Pulses Research, Kanpur-208 024, Uttar Pradesh
4.	Forages	AICRP-Forages, ICAR-Indian Grassland and Fodder Research Institute (IGFRI), Near Pahuj Dam, Gwalior Road, Jhansi-284 003, Uttar Pradesh
		ICAR-Indian Grassland and Fodder Research Institute (IGFRI), Near Pahuj Dam, Gwalior Road, Jhansi-284 003, Uttar Pradesh
5.	Field crops	Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Indian Council of Agricultural Research, Almora-263 601, Uttarakhand
6.	Groundnut	ICAR-Directorate of Groundnut Research (DGR), PO Box 5, Ivnagar Road, Junagadh-362 001, Gujarat
7.	Fibres	ICAR-Central Research Institute for Jute and Allied Fibers (CRIJAF), Barrackpore, Kolkata-700 120, West Bengal
8.	Maize	ICAR-Indian Institute of Maize Research (IIMR) Ludhiana, Punjab-141 004
9.	Oilseeds (castor, sunflower, safflower)	ICAR-Indian Institute of Oilseeds Research (IIOR), Rajendranagar, Hyderabad-500 030, Andhra Pradesh
10.	Pearl millet	All India Coordinated Pearl Millet Improvement Project, Rajasthan Agricultural University, ARS, Mandore, Jodhpur-342 304, Rajasthan
11.	Rapeseed and mustard	ICAR-Directorate of Rapeseed-Mustard Research (DRMR), Sewar, Bharatpur-321 303, Rajasthan
12.	Rice	ICAR-National Rice Research Institute (NRRI), Cuttack-753 006, Orissa
13.	Rice and Lathyrus	Indira Gandhi Krishi Vishwavidyalaya (IGKVV), Raipur-492 006, Madhya Pradesh
14.	Sesame and Niger	AICRP on Sesame and Niger, Jawaharlal Nehru Krishi Viswa Vidyalaya Campus (JNKVV), Jabalpur-482 004, Madhya Pradesh
15.	Small millets	AIC Small Millets Improvement Project, Project Coordinating Unit (Small Millets) UAS GKVK, Bengaluru-560 065, Karnataka
16.	Sorghum	ICAR-Indian Institute of Millets Research (IIMR), Rajendranagar, Hyderabad-500 030, Andhra Pradesh
19.	Soybean	ICAR-Directorate of Soybean Research (DSR), Khandwa Road, Indore-452 001, Madhya Pradesh

(continued)

Table 4.4 (continued)

S. no.	Crop(s)	Name of crop-based institute
20.	Sugarcane	ICAR-Sugarcane Breeding Institute (SBI), Coimbatore-641 007, Tamil Nadu
		ICAR-Indian Institute of Sugarcane Research (IISR), Raibareli Road, P.O. Dilkusha, Lucknow-226 002, Uttar Pradesh
21.	Underutilized crops	ICAR-National Bureau of Plant Genetic Resources (NBPGR), Pusa Campus, New Delhi-110 012
22.	Wheat and barley	ICAR-Indian Institute of Wheat and Barley Research (IIWBR), Post Box No-158, Agrasain Marg, Karnal-132 001, Haryana
23.	Agroforestry crops	AICRP on Agroforestry, ICAR-National Research Centre for Agroforestry, Jhansi-Gwalior Road, Near Pahuj Dam, Jhansi-284 003, Uttar Pradesh
24.	Arid fruits	ICAR-Central Institute for Arid Horticulture (CIAH), Sri Ganganagar Road, NH-15, Beechwal, Bikaner-334 006, Rajasthan
25.	Banana	ICAR-**National Research Centre for Banana (NRCB),** Thogamalai Road, Thayanur Post, Tiruchirappalli-620 102, Tamil Nadu
26.	Cashew	ICAR-Directorate of Cashew Research (DCR), Post Darbe, Puttur-574 202, Dakshina Kannada, Karnataka
27.	Citrus species	ICAR-National Research Centre for Citrus, Amravati Road, Nagpur-440 010, Maharashtra
28.	Flowers	ICAR-Directorate of Floricultural Research (DFR), College of Agriculture campus, Shivajinagar, Pune 411 005, Maharashtra
29.	Grapes	ICAR-National Research Centre for Grapes, P.B. No. 3, P.O. Manjri Farm, Solapur Road, Pune-412 307, Maharashtra
30.	Litchi, bael, aonla and jackfruit	ICAR-National Research Centre for Litchi, Mushahari, P.O. Ramna, Muzaffarpur-842 002, Bihar
31.	Medicinal and aromatic plants	ICAR-Directorate of Medicinal and Aromatic Plants Research (DMAPR), Boriavi-387 310, Anand, Gujarat
32.	Mango	ICAR-Central Institute for Subtropical Horticulture (CISH), Rehmankhera, Kakori-Lucknow-227 107, Uttar Pradesh
33.	Subtropical fruits	ICAR-Central Institute for Subtropical Horticulture (CISH), Rehmankhera, Kakori-Lucknow-227 107, Uttar Pradesh
34.	Mulberry	Central Sericultural Germplasm Resources Centre, Central silk Board, Ministry of Textile, Government of India, P.B.-44, Thally Road, Hosur-635 109, Dharmapuri, Tamil Nadu
35.	Oil palm	ICAR-Indian Institute of Oil Palm research (IIOPR), Pedavegi-534 450, West Godavari District, Andhra Pradesh
36.	Onion and garlic	ICAR-Directorate of Onion and Garlic Research (DOGR), Rajgurunagar, Pune-410 505, Maharashtra
37.	Orchids	ICAR-National Research Centre for Orchids, Pakyong-737 106, Sikkim

(continued)

Table 4.4 (continued)

S. no.	Crop(s)	Name of crop-based institute
38.	Ornamental and non-traditional crops	CSIR-National Botanical Research Institute (NBRI), PO Box No. 436, Rana Pratap Marg, Lucknow-226 001, Uttar Pradesh
39.	Plantation crops	ICAR-Central Plantation Crop Research Institute (CPCRI), Kudlu, PO, Kasaragod-671 124, Kerala
40.	Potato	ICAR-Central Potato Research Institute (CPRI), Shimla-171 001, Himachal Pradesh
41.	Spices	AICRPS, ICAR-Indian Institute of Spices Research (IISR), Marikunnu P.O., Kozhikode (Calicut), Kerala-673 012
42.		ICAR-Indian Institute of Spices Research (IISR), Marikunnu P.O., Kozhikode-673 012, Calicut, Kerala
43.	Tea	UPASI Tea Research Foundation, Tea Research Institute, Nirar Dam, Valparai-642 127, Coimbatore, Tamil Nadu
		Tea Research Association (TRA), Tocklai Experimental Station, Jorhat-785 008, Assam
44.	Temperate horticultural crops	ICAR-Central Institute for Temperate Horticulture (CITH), Old AirPort Road, Rangreth, Srinagar, Kashmir-190 007
		ICAR-National Bureau of Plant Genetic Resources, Regional Station, Phagli, Shimla-171 004, Himachal Pradesh
45.	Tobacco	ICAR-Central Tobacco Research Institute (CTRI), Bhaskar Nagar, Rajahmundry-533 105, Andhra Pradesh
46.	Tropical fruits	ICAR-Indian Institute of Horticultural Research (IIHR), Hesaraghatta lake post, Bengaluru-560 089, Karnataka
		All India Coordinated Research Projection Tropical Fruits, ICAR-Indian Institute of Horticultural Research (IIHR), Hesaraghatta lake post, Bengaluru-560 089, Karnataka
47.	Tuber crops	ICAR-Central Tuber Crops Research Institute (CTCRI), Sreekaryam, Thiruvananthapuram-695 017, Kerala
		All India Coordinated Research Project on Tuber Crops, ICAR-Central Tuber Crops Research Institute (CTCRI), Sreekaryam, Thiruvananthapuram-695 017, Kerala
48.	Vegetables	ICAR-Indian Institute of Vegetable Research (IIVR), Post Bag No. 01; P.O. Jakhini (Shahanshapur), Varanasi-221 305, Uttar Pradesh
		ICAR-Indian Agricultural Research Institute (IARI) Regional Station, Katrain, Kullu-175 129, Himachal Pradesh
		G.B. Pant University of Agriculture and Technology, Pantnagar-263 145, Distt, Udham Singh Nagar, Uttarakhand
49.	Ornamental crops	ICAR-Indian Institute of Horticultural Research (IIHR), Hesaraghatta lake post, Bengaluru-560 089, Karnataka

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Nutritive Vegetable Production and Protection with the Use of Vrikshayurveda-based Herbal *Kunapajala*

5

S. P. S. Beniwal

Abstract

It is through the research efforts made by the Indian Council of Agricultural Research through its different institutes and national research programmes and the State Agri-varsities that the productivity and production of vegetables in India have lately increased. However, diseases and insect-pests continue to be a threat to vegetable production in the country for which excessive use of pesticides by farmers has resulted in ecological, environmental and human health issues. Use of organic practices/methods for the cultivation of vegetables is one possible solution for this in which the role of liquid biofertilizers becomes important. A bioformulation known as herbal *Kunapajala*, developed by the Asian Agri-History Foundation from the original *Kunapajala* described in the book Vrikshayurveda by Surapala (c. 1000 CE), has shown a great promise in the organic cultivation of different crops including vegetable crops. Herbal *Kunapajala* can be easily prepared with cow dung, cow urine, jaggery (*gud*), germinated whole urd bean, mustard or neem oil cake, rice husk water (rice husk first boiled in water for 10–15 min and then cooled for 2 days), finely chopped field weeds and water in anaerobic conditions to promote fermentation. It is a fully fermented, multipurpose bioformulation, which supports excellent plant growth and development with good-quality yields and also protects the plants from major biotic stresses and also from some abiotic stresses (protection from cold/frost and mild drought). Importantly, the farmer has tremendous flexibility in its preparation, and being liquid, it can be used in vegetables in several different ways. Herbal *Kunapajala* has been successfully used in tomato, brinjal, capsicum, okra, chillies, cucumber, cowpea and Amaranthus and found to enhance

S. P. S. Beniwal (✉)
Asian Agri-History Foundation, GB Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

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their general growth and fruiting of plants as compared with the chemical fertilizers. It has also been shown to improve the nutritive value of vegetable crops. In tomato, its application improves the quality of fruits and amount of lycopene, taste and flavour, appearance of fruits as they look fresh and more attractive, and shelf life of fruits, which is useful for transportation and marketing. Thus, herbal *Kunapajala* has a great potential in the organic farming of vegetable crops.

Keywords

Vrikshayurveda-based · Herbal *Kunapajala* · Nutritive vegetables · Vegetable production · Vegetable protection

5.1 Introduction

A wide variety of vegetable crops are grown in India because of its varied agro-climatic conditions. Thanks to the research efforts made by the Indian Council of Agricultural Research through its different institutes and research programmes and the State Agri-varsities that the productivity and production of vegetables in India has been increased. As a result, the production of vegetables in the country has significantly increased over the past years and was 189 mt in the year 2020. In spite of good efforts of different vegetable crop improvement programmes in the country that have resulted in the development of improved disease and insect-pest-resistant varieties in different vegetable crops, they are affected with a number of diseases and insect-pests that adversely affect their productivity and production and thus are a major threat to profitable vegetable production in the country.

Vegetable crops are affected with a number of diseases and insect-pests of which the major diseases are damping off, early blight, late blight, leaf spots, powdery mildew and fruit rots, and the major insect-pests are aphids, caterpillars, cutworms, thrips, whiteflies and mites (Singh 2017). Although vegetable varieties resistant to diseases and insect-pests are available, the major method of control of these diseases and insect-pests is achieved through the use of fungicides and insecticides, respectively. Economic damage in vegetable crops especially due to insect-pests has led to excessive pesticide use by farmers, which has resulted in ecological, environmental and human health issues. The highest use and contamination of pesticides were found in Kerala followed by Uttar Pradesh (Rai 2015). As a result, most vegetables in the markets were found to be contaminated with pesticides such as Chlorpyrifos, Monocrotophos, Endosulfan, DDT and Lindane (Nishant and Upadhyay 2016). Thus, an important challenge in vegetable production is to produce healthy and nutritive vegetables by protecting them from diseases and insect-pests through the use of organic practices/methods. The initiative to meet this challenge was taken by some institutions, non-governmental organizations, social activists and individual farmers who started using organic practices/methods for the cultivation of vegetables. Among them, different types of liquid biofertilizers developed are being used.

5.2 Liquid Biofertilizers for Organic Farming

Among the methods used for organic production of crops, liquid biofertilizers of different names have been used, which are basically Vrikshayurveda-based and taken from the book Vrikshayurveda (c. 1000 CE) by Surapala (Sadhale 1996). Several variants of these liquid biofertilizers are now being used for organic farming (Vrikshayurveda, *Panchagavya*, *Jeevamrit*, *Beejamrit*, compost tea, *Matka khad*, Vermiwash and *Amrutpani*), which have been proposed by different workers with the objective of improving soil health and enhancing the biological efficiency of crop plants and food production for eco-friendly nutrient and disease management under organic farming situations. Although the commonly used bio-liquid formulations help grow food which is free from health hazards posed by synthetic chemicals (fertilizers, insecticides and pesticides), they are generally not very effective in controlling various crop biotic/abiotic factors, which end up reducing the crop productivity, a common experience of smallholder farmers who commonly use them due to their poor investment capacity. Thus, farmers are required to use different bioformulations during the crop season for different purposes.

Organic formulations based on cow urine and dung as such and/or after addition of neem leaves, mustard oil cake, mustard and rice husk/straw, etc. upon anaerobic fermentation provide not only useful plant nutrients for restoring fertility of the depleted soils and food for biotic activity but also other organic chemical molecules which have anti-fungal properties and are very helpful as biopesticides, biofertilizers and pest repellents (Nene 2006; Deshmukh et al. 2012; Parmar 2009, 2017, 2019; Naresh and Dhaliwal 2020; Jidesh 2019; Beniwal and Pandey 2020). Thus, the Vrikshayurveda-based, especially the fully fermented, concoctions help farmers grow crops and foods which are free from health hazards of chemical fertilizers, insecticides and pesticides without affecting crop productivity.

5.3 *Kunapajala*: The World's First Fermented Liquid Fertilizer

Almost all texts on Vrikshayurveda (from 800 CE through mid-1900 CE) strongly prescribe preparation of *Kunapajala*. However, it is the 1000-year-old book Vrikshayurveda by Surapala which described a new concept of a biofertilizer under the generic name '*Kunapajala*' (Sadhale 1996), which was a fully fermented, non-vegetarian liquid biofertilizer prepared by boiling animal products (meat, bones and fish) and by using locally available ingredients such as sesame (*Sesamum indicum* L., *tila* in Hindi) oil cake, germinated whole black gram (urd bean), milk, ghee, honey (to aid fermentation) and rice husk. This was the first fertilizer given to the world by Surapala. He had used *Kunapajala* in fruit trees, which supported excellent growth and development. Since then, a considerable progress has been

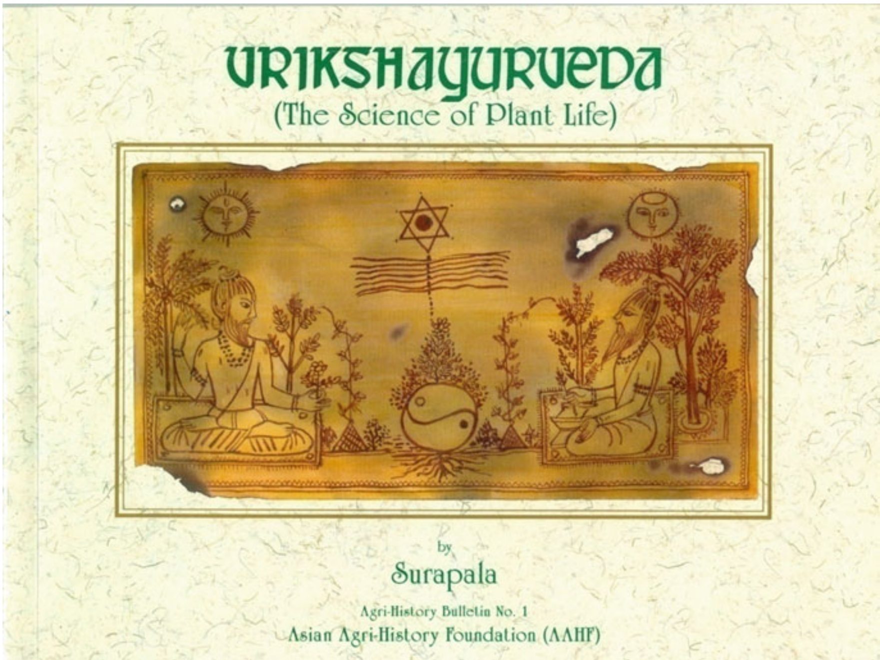

Fig. 5.1 Vrikshayurveda book by Surapala (c. 1000 CE)

made on these aspects. The descriptions of *Kunapajala* given by different authors are almost similar to those given by Surapala, and thus its preparation allows considerable flexibility to farmers in choosing constituents and their proportions and also in the procedure. However, preparation and use of *Kunapajala* had been virtually forgotten until AAHF published the English translation of Vrikshayurveda by Surapala in 1996 (Sadhale 1996). Even after its publication and description of *Kunapajala*, hardly any agricultural scientist took any interest in understanding and experimenting with it till Valmiki Sreenivasa Ayangarya first published a short note 'Herbal *Kunapa*' in 2004 (Ayangarya 2004). He called it *Sasyagavya*. Later, a herbal *Kunapajala* was developed and described by Nene (2012), which is now commonly used by farmers. Comparison of *Kunapajala* with other similar products has also been made (Nene 2018). Because of its historical origin and use, *Kunapajala* has been called the organic liquid manure of antiquity (Nene 2006) (Fig. 5.1).

5.4 Herbal *Kunapajala*: A Multipurpose Bioformulation

Nene (2006), considering the limited use of the original non-vegetarian *Kunapajala* in India, developed a fully fermented vegetarian *Kunapajala* by substituting the animal by-products with cow dung and cow urine but retained other vegetarian ingredients used in the formulation of original *Kunapajala*. He developed a herbal

Kunapajala recipe by adding chopped herbal plants (mostly random weeds from the fields) into the vegetarian *Kunapajala* fermentation tank (commonly used 200 L plastic drum) (Nene 2012). This was to take care of diseases and insect-pests affecting crop plants and to avoid the necessity of using different bioformulations during the crop season for different purposes. The fully fermented herbal *Kunapajala* is a multipurpose fully fermented bioformulation as it not only supports an excellent plant growth and development with good yields but also protects the plants from major biotic stresses and also from some abiotic stresses (protection from cold/frost and mild drought). Thus, it can serve the function of an eco-friendly nutrient, water, disease and soil health management system. An extension leaflet on Vrikshayurveda's herbal *Kunapajala* has been prepared for the use of farmers in Hindi (Asian Agri-History Foundation 2020). Now, there is a need for additional research for determining the respective possible effects/roles of each of the ingredients used in the preparation of herbal *Kunapajala* on soil biota and plant growth.

AAHF's experience in using Vrikshayurveda's herbal *Kunapajala* and its different modified preparations based on it from 2004 to 2012 in tea had provided excellent results in protecting the crop from biotic and to some extent abiotic stresses and improving crop growth and productivity (Ayangarya 2006). It has helped tea growers in Darjeeling, Doab and Dooars districts converting two-thirds of their inorganic tea gardens to organic ones in northern West Bengal (Parmar 2009, 2017, 2019). Very similar and encouraging results have been obtained in several different field, vegetable and fruit crops in Kannur and adjoining districts of Kerala state since 2017 (Jidesh 2019). Similar work initiated by AAHF and GBPUA&T in the hilly areas of Nainital district in November 2019 has further confirmed that herbal *Kunapajala* is a multipurpose bioformulation and works as a biofertilizer providing nourishment to soil and nutrition to plants; provides protection to plants from major diseases and insects; and also provides a fair protection to plants from cold/frost damage and mild drought situations, thus confirming similar and earlier observations from Darjeeling, Doab and Dooars districts in northern West Bengal and Kannur district in Kerala state. Similarly, use of herbal *Kunapajala* in rice crop at the Norman E. Borlaug Crop Research Centre at GBPUA&T, Pantnagar, during the 2019 *kharif* (rainy) season, produced very healthy crop (almost free from false smut disease) with a yield of 65 quintals/ha (Sunita Pande, Personal communication). Relevance of Vrikshayurveda and traditional knowledge for eco-friendly sustainable agriculture to meet MDGs in India have been appropriately discussed (Beniwal et al. 2020).

5.5 Preparation of Herbal *Kunapajala*

Herbal *Kunapajala* can be prepared with the following ingredients: (1) cow dung, 15 L; (2) cow urine, 15 L; (3) jaggery (*gud*), 2 kg; (4) germinated whole urd bean, 2 kg; (5) mustard or neem oil cake, 2 kg; (6) rice husk water (rice husk first boiled in water for 10–15 min and then cooled for 2 days), 2–3 kg; (7) finely chopped weeds, 20 kg; and (8) water, 10 L.

Take a 200 L plastic drum which can be closed with a tight lid. Place the first five ingredients above in the drum, then pour 10 L of water into it and then stir the contents well with a strong 5-ft-long wooden stick. Then add 20 kg of chopped weeds into the drum, stir and then fill the drum with water leaving 25–30 cm (9–10 inch) space above from the lid. Stir the contents well with the stick by stirring for 5 min each both clockwise and anticlockwise. Tighten the lid and leave the drum in a shade. Next morning, open the lid and stir the contents well clockwise and anticlockwise for 5 min each. One can see the bubbles in the drum after opening the drum. The same process is to be repeated in the evening and till the day when one does not observe the bubbles. Cessation of bubbles would indicate that the fermentation process has stopped and the herbal *Kunapajala* is ready. The completion of fermentation and preparation of herbal *Kunapajala* would normally take 12–15 days in summer months whereas 21–30 days in winter (cooler months). Strain the prepared herbal *Kunapajala* through a coarse cheese cloth to remove the debris. A second staining is recommended if this *Kunapajala* is to be used for field sprays, drip/sprinkler irrigation, etc. (Figs. 5.2 and 5.3).

5.6 Importance of Herbal *Kunapajala* in Organic Farming

Herbal *Kunapajala* is a fully fermented liquid biofertilizer, which nourishes the soil, improves the soil through the growth of earthworms and useful microbes, improves the soil health, nourishes the plant resulting in enhanced vegetative and reproductive growth and better productivity and provides effective control and management of insect-pests and diseases. It has been observed that it protects the crops from light frost and also mild drought situation as it improves the water-holding capacity of soil. According to our experience and belief, it is one fully fermented organic bioformulation that can make an organic farming successful. Interestingly, because of its multipurpose characteristics, a farmer can do organic farming with it without the need of using any other organic material, especially useful microbes such as *Trichoderma* and *Beauveria*, micronutrients, insecticides and fungicides, as herbal *Kunapajala* can successfully provide all of these to soil and plants. Another important point is that the farmer can himself or herself prepare it easily and can include herbal plants in making it based on the requirements. For example, the farmer can include neem cake in its preparation if nematodes/soil insects are a problem in his or her field. Similarly, if a farmer has the knowledge of particular diseases that affect his or her crop, he or she can include specific herbal plants that are known to be effective against those diseases while preparing the herbal *Kunapajala.* According to our experience, it is only in special situations that there would be a need to use any other organic biofungicides or bioinsecticides. For such situations, we have developed different biofungicides/biopesticides to control the prevailing diseases and insect-pests (Ayangarya 2006; Beniwal and Pandey 2020; Parmar 2019).

Fig. 5.2 Preparation of herbal *Kunapajala*. (**a**) A 200 L plastic drum. (**b**) Oil cake and germinated black gram. (**c**) Chopped weeds/plants. (**d**) Cow dung

Herbal *Kunapajala* is made from easily available ingredients, is easy to make and has flexibility in its preparation based on the needs. The farmer has a choice in choosing the constituents and proportions as per requirements (choice of oil cake and herbal plants and their ratios and procedure). It is eco-friendly, non-hazardous and user friendly with tremendous fertilizer value and affordable low cost. It is a liquid and reaches roots in a short time. Its complex ingredients are fermented and broken into simple low-molecular-weight products, which are easily available to plants resulting in quick and faster plant growth and development (Jani et al. 2017).

Fig. 5.3 Prepared herbal *Kunapajala* (left) and its demonstration in Uttarakhand (right)

5.7 Using Herbal *Kunapajala* in Vegetable Crops

The prepared herbal *Kunapajala* can be used in vegetable crops either with or without dilution of 1:10 in the following different ways:

- Treatment (dipping) of seed/rhizome/suckers/seedlings before sowing/transplanting (1:10 dilution)
- Use with irrigation water (fertigation) in seedling nursery (undiluted @ 90–100 L/acre)
- Pre-sowing irrigation fertigation of the field (undiluted @ 90–100 L/acre)
- Fertigation at each irrigation water for crops (undiluted @ 90–100 L/acre)
- Use in foliar sprays (1:10 dilution at 10–15-day interval, normally 2–3 times)
- Easily applied through drip/sprinkler/microirrigation and hydroponic

5.8 Usefulness of *Kunapajala* in Different Vegetable Crops

Herbal *Kunapajala* has been successfully used in tomato, brinjal, capsicum, okra, chillies, cucumber, cowpea and Amaranthus. It has been observed that the application of *Kunapajala* enhances general growth and fruiting of plants as compared with chemical fertilizers (Asha 2006). This has also been observed in different vegetables applied with herbal *Kunapajala* in Uttarakhand (Beniwal, personal observation) and Kerala (Jidesh 2019). Herbal *Kunapajala* application has also been observed to extend the flowering and fruiting phases, resulting in 20–30% higher yields (fruits) and bigger size fruits. It is able to protect crops from diseases and insects due to production of higher amounts of glycine betaine and proline content—which is

Fig. 5.4 Effect of herbal *Kunapajala* use on brinjal

useful for osmotic adjustment and providing resistance to abiotic stresses in leaf. It also improves appearance of fruits as they look fresh and more attractive and also improves the shelf life of fruits, which is useful for transportation and marketing.

Herbal *Kunapajala* is known to improve plant metabolism, which on the one hand induces growth and higher yield and on the other hand results in enhanced biochemical defence, which lowers pests and diseases. It makes plants energy sufficient and thus improves their photosynthetic efficiency. Inclusion of energy components can increase the rate of linear electron transport and improve stomatal conductance, leading to better diffusion of CO_2 towards carboxylation sites. Higher photosynthetic rate leading to continuity in simple carbohydrate formation results in higher starch reserve and higher energy. Healthy plants can optimize transportation stream and photosynthetic efficiency, resulting in higher crop productivity, better immunity leading to reduction of pests and diseases, increase in secondary metabolites resulting in better product quality, and also sustainability in production.

It is believed that during fermentation of herbal *Kunapajala*, intermediate products of decomposition, organic acids, combine to form ammonium salts which prevent the loss of ammonia and results in the formation of nitrates. Use of herbal *Kunapajala* reduces the loss of organic matter, which results in greater conservation of organic matter and nitrogen. During fermentation, growth promoters are produced in herbal *Kunapajala* which helps enhance plant and reproductive growth. There is a likelihood of production of phytochemicals due to addition of different weeds/ medicinal plants, which may enhance plant growth.

In our experience, herbal *Kunapajala* has been shown to improve the growth and productivity in brinjal, tomato, capsicum, okra, chillies, cucumber, cowpea and Amaranthus. This is shown in Figs. 5.4, 5.5, 5.6, 5.7, 5.8, 5.9 and 5.10.

Fig. 5.5 Effect of herbal *Kunapajala* on tomato production

Fig. 5.6 Effect of herbal *Kunapajala* use on capsicum production

Fig. 5.7 Effect of herbal *Kunapajala* on okra production

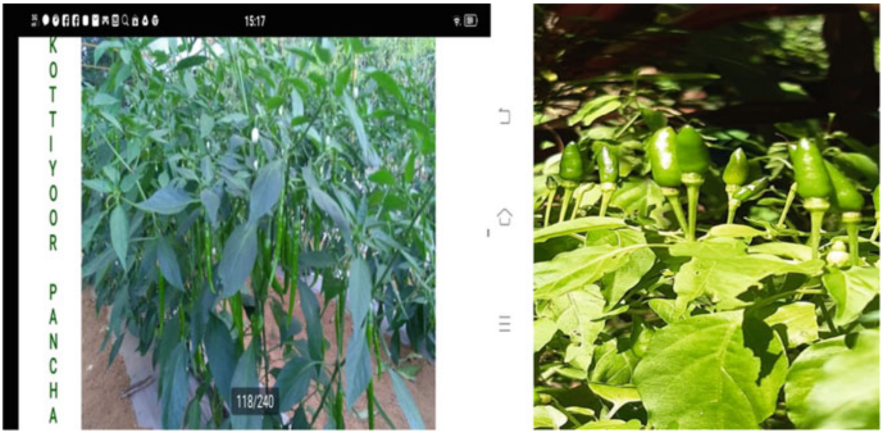

Fig. 5.8 Effect of herbal *Kunapajala* on chillies

5.9 Nutritive Value of Organic Vegetables

It is recognized that organically produced crops contain significantly more vitamin C, iron, magnesium and phosphorus and significantly less nitrates than the conventional crops (Worthington 2001). They have a better quality protein and nutritionally significant minerals and lesser amount of some heavy metals. Considering these qualities, they attract better consumer attention and fulfil better satisfaction. These differences occur due to differences in the management of soil fertility that affect soil dynamics and plant metabolism as a result of which differences in plant composition and nutritional quality are observed. Soil managed organically has

Fig. 5.9 Effect of herbal *Kunapajala* on cucumber production

Fig. 5.10 Effect of herbal *Kunapajala* on bean (left) and Amaranthus (right)

more microorganisms, which produce many compounds including citrate and lactate that help plants by making them more available to plant roots that combine with soil minerals. Nitrogen from fertilizer affects the amounts of vitamin C and nitrates as well as the quantity and quality of protein produced by plants. As the organically managed soils present plants with lower amounts of nitrogen than chemically fertilized soils, it is expected that organically produced crops would have more vitamin C, less nitrates and less protein but of a higher quality.

5.10 Herbal *Kunapajala* and Nutritive Value of Tomato Fruits

Effect of herbal *Kunapajala* on the nutritive value of tomato fruits was studied in comparison with the conventional and organic farming (Deshmukh et al. 2012). The following changes were observed in the herbal *Kunapajala*-treated plants: (1) increase in the total acids, fibre content, total solids and ash; (2) increase in the biochemical constituents (soluble proteins, total carbohydrates and polyphenols) and also the taste, flavour and nutritional value of fruits; (3) increased lycopene—interesting from coronary health point of view; (4) higher ascorbic acid, proline and glycine betaine obtained, which are useful for minimizing oxidative stress; (5) increase in oxidative enzymes that confer antioxidant properties; and (6) higher carotenoids, which have a role in protecting cells from harmful effects of light and air and antioxidants. All these positive changes in tomato fruits due to herbal *Kunapajala* treatment are useful for the health of fruits as well as the consumer.

5.11 Conclusion

Vegetables are an integral and important part of the diets of Indians. Lately, their productivity and production have increased through the research efforts made by the Indian Council of Agricultural Research through its different institutes and All India Coordinated Research programmes, State Agri-varsities and the private sector. In spite of the fact that a number of disease-resistant/tolerant varieties have been developed, diseases and insect-pests continue to be a threat to vegetable production in the country. For their control, excessive pesticides are being used by farmers, which have resulted in ecological, environmental and human health issues. One possible solution for this situation is the use of organic practices/methods for the cultivation of vegetables or the use of biofungicides/biopesticides to control diseases and insect-pests. In this, the role of liquid biofertilizers becomes important, several of which are being used by the farmers these days. In this list, there is also a bioformulation known as herbal *Kunapajala*, developed by the Asian Agri-History Foundation (AAHF) from the original *Kunapajala* described in the book Vrikshayurveda by Surapala (c. 1000 CE); it has shown a great promise in successful organic cultivation of different crops including vegetable crops and for the control of diseases and insect-pests. The AAHF, the proponent of herbal *Kunapajala*, has validated its effectiveness in different crops since 2004 in different crops and states and found it extremely useful. For the last few years, its use has been extended to smallholder farmers in Kerala and Uttarakhand who grow several different crops on their farms including the vegetable crops. These efforts have provided very useful and encouraging results in different vegetable crops and helped farmers in increasing productivity and production of their organic vegetable crops and thus their household income. They are able to organically cultivate their vegetable crops with the use of only herbal *Kunapajala* and are able to sell their produce as organic to the local consumers and local markets. However, there is now a challenge to do further research into the 'why' and 'how' aspects of herbal *Kunapajala* to find the possible reasons behind its effectiveness in increasing productivity and quality of vegetable crops. Also, there is a need to make arrangements to make it available on market shelves for its easy availability especially for the urban users.

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Microgreens from Vegetables: More Nutrition for Better Health

6

Tanmay Kumar Koley and Vikramaditya Pandey

Abstract

Microgreens are a tiny form of young edible greens which are rich in flavor and nutrition. They are rich in vitamins, particularly vitamin E, mineral (Zn), and various bioactive compounds. Plants propagated by seeds are used for microgreen production. Plants are selected for microgreens based on seedling color, texture, flavor, and local demand. Microgreens are produced in basket or pot containing growing media such as coir, bark, peat moss, perlite, rock wool, coco peat, vermiculite, vermi-compost, and sphagnum peat. Media are sterilized and treated with Trichoderma for prevention of damping-off. Microgreens are commercially produced under protected condition with natural sunlight with low humidity and good air circulation. Irrigation is the main intercultural operation for microgreen production. Microgreens are usually harvested at 7−14 days after germination in summer season and slightly longer (14–28 days) in winter season. They are a highly perishable commodity, and pre-cooling is a major postharvest operation which reduces the postharvest losses. Microgreens are consumed as raw and used in salads, sandwich, and soups.

Keywords

Microgreens · Nutrition · Bioactive compounds · Protected condition · Postharvest

T. K. Koley (✉) · V. Pandey
ICAR-Research Complex for Eastern Region, Patna, Bihar, India

ICAR-Krishi Anusandhan Bhawan, New Delhi, India

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In the twenty-first century, due to poor lifestyle and food habit, the occurrence of different diseases like cancer, diabetes, obesity, cardiovascular disease, and hypertension is increasing both in developed and developing countries. Although various synthetic medicines are available to overcome these diseases, most of them are costly and have side effects. Thus, to overcome this problem, scientists are identifying newer natural sources of nutritional compound. Recently, microgreens from vegetables and other edible plants have received wide attention due to their dense source of nutrition.

Microgreens are a tiny form of young edible greens produced from various kinds of vegetables, herbs, and plants, harvested as seedling which is rich in flavor and nutrition. It has three basic parts: a central stem, two cotyledon leaves, and typically the first pair of very young true leaves which are not more than 4–14 days old depending on the species. Microgreens first became popular in the middle of 1990s in California, USA. However, the word "microgreens" was first documented in 1998. Later, it gained popularity among different upscale markets and restaurants as new culinary greens.

6.1 Why Microgreens?

Microgreens are richer sources of various micronutrients, especially vitamins and minerals. Some of the lipophilic vitamins are much higher in microgreens than mature parts. For example, vitamin E content of microgreens is up to 40 times higher compared to mature parts. Some of the recent reports reveal that some of the micronutrients like potassium and zinc are higher in microgreens. It is very interesting that antinutritional factors like nitrate and nitrite content are also low in microgreens. In addition to this, microgreens are dense sources of various bioactive compounds. Besides this, it can be easily produced using limited input, which will be useful for a person especially in urban or peri-urban settlings, where land is often a limiting factor. Furthermore, they can be produced throughout the year, since at young stages, generally the seedling does not require any specific weather condition. Given their short growth cycle, they can be grown without soil and without external inputs like fertilizers and pesticides, around or inside residential areas. Thus, they are practically chemical-free produce. Moreover, they are usually consumed raw; hence, there is no loss or degradation of thermolabile micronutrients through food processing.

6.2 Selection of Crops for Microgreen Production

Crop raised through seeds is used for microgreen production. The selection of the crop is based on seedling color, texture, flavor, and demand of the produce market. They should also have quick germination and be easily growing with high nutritive values. The most potential microgreens are found in the vegetable crops belonging to the family Amaranthaceae, Chenopodiaceae, Brassicaceae, and Apiaceae. Few crops belonging to the family Fabaceae are also suitable for microgreens (Table 6.1).

Table 6.1 Commonly used microgreens and predominant bioactive compounds

Family	Name	Scientific name	Color	Bioactive compounds
Brassicaceae	Arugula	*Eruca sativa* Mill	Green	Glucosinolates, phenolics
	Radish	*Raphanus sativus* L	Green to purplish green	Glucosinolates, phenolics, anthocyanins
	Mizuna	*Brassica rapa* L	Green	Glucosinolates, phenolics
	Pepper cress	*Lepidium bonariense* L.	Green	Glucosinolates, phenolics
	Purple knol khol	*Brassica oleracea* var. *gongylodes* L.	Purplish green	Glucosinolates, phenolics, anthocyanins
	Purple mustard	*Brassica juncea* L.	Purplish green	Glucosinolates, phenolics, anthocyanins
	Red cabbage	*Brassica oleracea* var. *capitata* L.	Purplish green	Glucosinolates, phenolics, anthocyanins
	Pak choi	*Brassica rapa* var. *chinensis* L.	Reddish green	Glucosinolates, phenolics, anthocyanins
	Tatsoi	*Brassica rapa* subsp. *narinosa* Hanelt	Reddish green	Glucosinolates, phenolics, anthocyanins
	Wasabi	*Wasabia japonica* Matsum.	Green	Glucosinolates, phenolics
	Broccoli	*Brassica oleracea* var. *italica* L.	Green	Glucosinolates, phenolics
Fabaceae	Lentil	*Lens culinaris* Medikus	Green	Phenolics, folic acid
	Pea tendrils	*Pisum sativum* L.	Green	Phenolics, folic acid
	Bengal gram	*Cicer arietinum* L.	Green	Phenolics, folic acid
	Alfalfa	*Medicago sativa* L.	Green	Phenolics, folic acid
	Methi	*Trigonella foenum-graecum* L.	Green	Phenolics, folic acid
Amaranthaceae	Amaranthus	*Amaranthus tricolor* L.	Green to red	Phenolics, betalains
Chenopodiaceae	Swiss chard	*Beta vulgaris* var. *cicla L.*	Green	Phenolics, betalains
	Palak (Fig. 6.1)	*Beta vulgaris* var. *bengalensis L.*	Green to reddish green	Phenolics, betalains
	Quinoa	Chenopodium quinoa Willd	Green to reddish green	Phenolics, betalains
	Orach	*Atriplex hortensis L.*	Red	Phenolics, betalains

(continued)

Table 6.1 (continued)

Family	Name	Scientific name	Color	Bioactive compounds
	Spinach	*Spinacia oleracea L.*	Red to reddish green	Phenolics, betalains
	Beet root	*Beta vulgaris L.*	Reddish green	Phenolics, betalains
Apiaceae	Carrot	*Daucus carota* L.	Green to purplish green	Phenolics, polyacetylene
	Coriander	*Coriandrum sativum L.*	Green	Phenolics, polyacetylene
	Celery	*Apium graveolens L.*	Green	Phenolics, polyacetylene
Poaceae	Popcorn shoots	*Zea mays L.*	Yellow	Carotenoids
Lamiaceae	Basil	*Ocimum basilicum L.*	Green to greenish purple	Phenolics
Convolvulaceae	Water spinach (Fig. 6.2)	*Ipomoea aquatica* Forssk.	Green	Phenolics
Polygonaceae	Sorrel	*Rumex acetosa L.*	Green to reddish green	Phenolics, betalains
	Buckwheat	*Fagopyrum esculentum* Moench	Green to reddish green	Phenolics, betalains

Various color shades are available in these families due to the presence of various pigments like chlorophyll, carotenoids, anthocyanin, and betalains. Chlorophyll provides lush green to deep green colors to microgreens. Carotenoids provide yellow color to microgreens. Two yellow-colored microgreens are popular in the Western market, viz. yellow popcorn shoot and yellow pea tendrils, which were achieved through etiolation. Anthocyanins provide purple coloration to microgreens belonging to families Brassicaceae and Apiaceae. Betalains mainly found in plants belonging to families Amaranthaceae and Chenopodiaceae provide vivid red-pink to yellow colors. Microgreens from Brassicaceae and Apiaceae have distinct flavor, making them suitable for garnishing various dishes. Chickpeas have sour taste, whereas fenugreek is bitter in taste.

6.3 Production Techniques

Growing media: Microgreens are produced in basket or pot containing growing media. Wide range of media are available in market such as coir, wood fiber, bark, paper fiber, peat moss, perlite, rock wool, coco peat, vermiculite, vermi-compost,

Fig. 6.1 Palak microgreens

and sphagnum peat for production of microgreens. For better growth, microgreens require a media having good physiological properties. A media with pH of 5.5–6.5, low electrical conductivity (<500 MicroS/cm), water-holding capacity of 55–70% v/v, and aeration of 20–30% v/v is ideal for microgreen production. Peat and peat-based mixes are most common media used for microgreen production. However, many countries do not have enough natural peat moss resources. In addition to this, continuous extraction of peat moss from nature may pose environmental concerns. Thus, many researchers also explore the various alternative media such as coconut coir. However, it is poor physiological and microbiological stability, presence of high salts, and high bacterial and fungal counts that make it unsuitable for microgreen production. Many inorganic materials are also explored by researchers such as perlite or vermiculite. However, their production is energy demanding and thus becomes costly for commercial production of microgreens. Some of the synthetic materials such as rock wool and polyethylene terephthalate are cheaper, but they create disposal problems. Recently, many by-products from agro-industries such as jute fiber, kenaf fiber, or cotton have been used as low-cost and renewable media for microgreen production. Research efforts have been carried out to fortify various media with suitable nutrition or beneficial microbes for quality production and prevention of pathogen growth.

Fig. 6.2 Water spinach microgreens

Before use of media, it should be treated properly to prevent the growth of microbes, which causes damping-off. Heat pasteurization is the most common way of treating growing media and is traditionally done with steam. Some media like vermiculite and perlite are inherently sterile, which do not need any sterilization. However, sterilized media are also available commercially.

Recently, hydroponic techniques are used for the production of microgreens. Research on hydroponics reveals that microgreens produced using nutrient film techniques have higher yield compared to growing on tray containing media.

Seed treatment: In addition to media sterilization, seed treatments are sometimes advised to prevent pre- or postemergence damping-off caused by soilborne pathogenic fungi (Fig. 6.3). Due to very short pre-harvest period (9–18 days), chemical treatment is avoided. Seed treatment with biocontrol agents like *Trichoderma harzianum* and *T. virens* is recommended (Fig. 6.4). In addition to treatment with biocontrol agent, other seed treatments are sometimes followed to improve,

Fig. 6.3 Damping-off in alfalfa microgreens

Fig. 6.4 Seed treatment of pea using *Trichoderma*

standardize, and shorten the production cycle (Lee et al. 2004). Seed treatment such as simple water soaking, osmo-priming, matrix priming, and seed pre-germination is carried out to enhance germination. Researchers reported priming of radish, kale, and Amaranthus seeds in fine vermiculite at 12 °C and −1.0 MPa for 3-day advanced germination (Lee and Pill 2005). Lee et al. (2004) reported that matrix priming of beet and Swiss chard advanced the greenhouse establishment of their microgreens.

Seed sowing: Seeds for microgreen production should be collected from known source. Some of the microgreens germinate easily and grow quickly like alfalfa and lentil. They require high-light condition, preferably natural sunlight with low humidity, and good air circulation. Such conditions are ideal for microgreens and do not encourage the growth of dangerous pathogens.

For commercial production, preliminary germination test is required. It helps to understand the optimal seed rate. Seed rate varies with species, germination percentage, and desired shoot population density. Excessive seed density results in microgreens with soft elongated or stretched stems and smaller leaves with shorter shelf life. Approximately 10–12 seeds per square inch for smaller seeds (for example, arugula, mustard, watercress) and 6–8 seeds for larger seeds (for example, pea, chickpea, sunflower) are good (Di Gioia and Santamaria 2015). Researchers observed that if sowing rate is increased, it increases the fresh yield per unit area. However, it decreases mean shoot weight (Murphy and pill 2010; Murphy et al. 2010).

Growing condition: Microgreens are commercially produced under protected condition. It requires high-light condition, preferably natural sunlight with low humidity, and good air circulation. Light influences morphological appearance and physiological growth of microgreens. High light levels produce a stronger, longer lasting, and more flavorful microgreens than those grown under lower light conditions or artificial lights. It also influences the biosynthetic pathways and thus under various light qualities influences the kind and quantity of phytochemicals in microgreens. For the last few decades, light-emitting diodes (LEDs) have been used for vegetable production under greenhouse. Similarly, research has initiated to use LED with deferent spectral ranges and intensity to modulate the growth of microgreens. Red spectrum light was found to keep plants short, whereas blue spectrum light fuels vegetative growth and thus encourages height. They also influence nutritional composition of microgreens. Researchers demonstrated that by altering LED spectral quality, various oxygenated (lutein, neoxanthin, violaxanthin, and zeaxanthin) and hydrocarbon (α- and β-carotene) carotenoids were enhanced in microgreens (Table 6.2). However, the enhancement varies with species and growing condition. In addition to bioactive compounds, researchers also found that LED light has a positive effect on the enhancement of minerals and vitamins. Sometimes, antinutritional compounds such as nitrate and oxalate reduced in microgreens after exposure to light-emitting diodes.

Intercultural operation: During production of microgreens, the media should be kept moist, but not overly wet. Plastic trays should be placed on benches inside a greenhouse with a sprinkler system and favorable temperature of 26 ± 2 °C. Immediately after sowing, trays should be watered and covered with an inverted slotted tray for 48 h to keep humidity levels high. The seedlings should be carefully watered twice daily and kept moist until harvesting. Generally, weeds and disease are not observed because soilless sterilized media are used and grown under protected condition. Thinning is not necessary because microgreens are grown densely.

Table 6.2 Effect of light quality on bioactive compounds of microgreens

Microgreen species	Spectral quality of light	Observation	Reference
Mustard	Supplemental green light (520 nm)	Lutein/zeaxanthin ratio and β-carotene content increased	Brazaitytė et al. (2015)
Tatsoi, red pak choi	Standard blue/red/far red (447/638 and 665/731 nm)	High levels of carotenoids	Brazaitytė et al. (2015)
Buckwheat	Blue, red, and white LED	Improved the soluble solids and vitamin C contents	Choi et al. (2015)
Amaranth, basil, mustard, spinach, broccoli, borage, beet, kale, parsley, and pea	Basal HPS lighting, supplementary red LED for 3 days before harvest	Influenced the phenolics, ascorbic acid, anthocyanin content, and antioxidant properties	Samuolienė et al. (2012)
Perilla frutescens	Supplementary red LED (638 nm) 3 days before harvest	Increased the ascorbic acid and anthocyanins and decreased nitrates	Brazaitytė et al. (2013)
Basil	Supplemental greenhouse UV-A LED lighting	Improved antioxidant activity	Vaštakaitė et al. (2015)
Broccoli	Red and blue LED light	Increased the glucosinolate content	Kopsell et al. (2014)
Beta vulgaris L.	Compound light supplemental 33% blue (445 nm)	Increased vitamin E and α- and β-carotenes, lutein, violaxanthin, and zeaxanthin content	Samuolienė et al. (2017)
Purslane	Combination of red and blue spectrum	Reduced nitrate and oxalate content	Giménez et al. (2021)

6.4 Harvesting

Microgreens are usually harvested at 7–14 days after germination in tropical climate and slightly longer (14–28 days) in cold weather or temperate region with a height of 2.5–7.6 cm (1–3 inch) that varies from crop to crop and variety to variety and other environmental conditions. These are cut along with the stem and attached cotyledons/seed leaves with the help of scissors. If left for longer, they will begin to rapidly elongate and lose color and flavor.

At the stage of harvest, sorting and delivery of good hygiene practices are important. Harvesters will need gloves and harvesting equipment such as cutters, containers, and other instruments cleansed with proprietary cleanser before and after coming into contact with the microgreens. In addition to gloves, people coming into contact with the produce should be supplied with washable or disposable clothing and hair/beard nets. This will cut down on the risk of contamination.

Postharvest operation: Microgreens are highly perishable due to their high respiration rate. After harvesting, rapid senescence gives it very short shelf life, usually 3–5 days at ambient temperature. However, under low-temperature storage condition, its shelf life may extend up to 10–14 days. Thus, proper postharvest care is essential. After harvest, microgreens are thoroughly pre-cooled, which extends the shelf life. Hydrocooling could be the cheapest method of pre-cooling for microgreens. Treatment of microgreens with NaOCl (100 mg chlorine equivalent/L, pH 6.5) at the time of hydrocooling gives additional protection from microbial contamination. After that, moisture is removed and produce is packed in a plastic container. Precautions must be taken to avoid any microbial contamination during hydrocooling. In addition to chlorine treatment, other treatments also help to extend the shelf life of microgreens. For example, Kou et al. (2015) reported that treatment of calcium lactate in chlorinated water has improved the shelf life of broccoli microgreens. In another study, Chandra et al. (2012) have reported that washing with citric acid solution with ethanol spray improved the microbiological quality of Chinese cabbage microgreens.

In recent times, macro-perforated packaging materials have been used for increasing the shelf life of microgreens. Researchers have suggested that macro-perforated low-density polyethylene self-seal bag is better for radish and Roselle microgreens than macro-perforated polythene terephthalate clamshell container. All packaging containers need labeling to show where the product came from and when it needs to be used. Applying the harvesting date is advisable. From a local grower's perspective, having a harvesting date on the pack could reinforce the freshness of the product.

Microgreens are usually consumed raw, which minimizes the loss or degradation of heat-sensitive micronutrients through food processing. Unlike cooked vegetables, there are always chances of microorganism contamination in microgreens. Thus, major emphasis should be given during production to postharvest operation.

Use: Microgreens are used in salads, sandwich, and soups. They can be used to garnish Italian and Chinese fast food. It can also be a suitable material for stuffing paratha.

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On-Farm Organic Inputs Generation for Quality Vegetable Production

7

R. A. Ram

Abstract

Imbalanced use of agrochemicals has resulted in manifesting adverse effects on the environment, polluting natural resources. Soil fertility, especially deterioration in physical, chemical and biological properties, is becoming ubiquitous, threatening sustainability and produce quality. Soil organic carbon content in most of the cultivated lands has been reduced to >0.5%. Under these circumstances, maintenance of soil and crop health is the major constraint in today's agriculture. Now, numbers of macro- and micronutrients are becoming deficient in one or the other regions of the world. Other than multinutrients' deficiency, horticultural produce are loaded with pesticidal residues due to its frequent use. Most of the off-farm and outsourced organic inputs are not cost effective and also sometimes fail to meet the quality standards. Therefore, emphasis should be given to on-farm input production of quality vegetables. On-farm organic input production is a cheap and alternative tool to resolve the above issues in organic production of vegetables, which are a rich source of microbial consortia, macro- and micronutrients and plant growth-promoting substances. According to a conservative estimation, around 600–700 million tonnes of agricultural wastes (including 272 million tonnes of crop residues) are available in India every year. These organic wastes can be recycled through composting to reduce the cost of cultivation and improve the soil health. Besides these, the world generates 4.7 million metric tonnes of municipal soil wastes daily, and India contributes to 0.4 million metric tonnes. By 2050, 1750 acres of land will be required for dumping of these municipal wastes in India. These municipal organic wastes can be utilized for rooftop/terrace gardening for

R. A. Ram (✉)
Division of Crop Production, ICAR-CISH, Lucknow, Uttar Pradesh, India
e-mail: ra.ram@icar.gov.in

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growing of organic vegetables. These wastes are collected in digester bin and fortified with fast decomposers, viz. Amritpani, Jeevamrita, and cow pat pit, for fast conversion into good-quality compost for use of all seasons' vegetable crops on rooftop/terraces for food safety, exercise and happy life.

Keywords

Biodynamic compost · Bio-enhancers · Jeevamrita · Cow pat pit · *Ceratocystis fimbriata* · Rooftop gardening

7.1 Introduction

Indiscriminate use of chemical fertilizers, especially nitrogenous ones, has resulted in some regions manifesting adverse effects on the environment, polluting soil and groundwater resources. Soil quality, especially that of organic matter and micronutrient deficiencies, is becoming ubiquitous, threatening sustainability and quality of produce impacting nutritional security. Further, indiscriminate use of pesticides has led to the development of resistance to pests and pesticides, while irretrievably destroying the beneficial ones, viz. honeybees, pollinators, parasitoids, and predators, besides causing harmful pesticide residues in the end product, adversely impacting productivity and food safety (Ram and Pathak 2016).

Soils of arid and semi-arid zones are well suited for organic production because of low organic carbon, scarcity of water and high leaching properties of nutrients because organic farming practices improve physical, chemical and biological properties of the soil. Mulching, cover cropping, and similar practices reduce soil erosion by wind/water. Increasing consciousness about conservation of environment as well as of health hazards caused by agrochemicals has brought a major shift in consumer preference towards food quality, particularly in the developed countries. Global consumers are increasingly looking forward to organic food that is considered safe and hazard free. As per the excellent taste, wide variability with respect to varieties, nutritive and therapeutic values, and organic production of horticultural crops will have immense scope in domestic and export markets (Ram and Kumar 2019).

It is pertinent to record that with proper follow-up, all the organic production systems, i.e. biodynamic farming, *Rishi Krishi*, Natueco *Krishi*, *Panchagavya Krishi*, Homa organic farming and natural farming, have indicated high-quality production without the use of agrochemicals. There is a need to integrate few compactable techniques from these established system to develop a package of practices, which can easily be adopted by the common growers to assure sustainable organic production. Availability of quality organic inputs in the markets is not assured, and sometimes they do not meet the standard set by the BIS. Emphasis should be given to on-farm production of quality organic inputs for cost-effective and sustainable production.

There are few organic farming practices in which all the inputs, viz. composts, bio-enhancers and bio-pesticides, are produced with locally available materials. Composts are a rich source of nutrients, bio-enhancers are a rich source of beneficial microbes and bio-pesticides are an effective source for the management of various insect pests (Ram and Pathak 2019).

7.2 Crop Waste Management

Crop residues are natural resources with tremendous value to farmers. These residues are used as animal feed, composting, thatching for rural homes and fuel for domestic and industrial use. About 25% of nitrogen and phosphorus each, 50% of sulphur and 75% of potassium uptake by cereal crops is retained in residues, making them valuable sources of nutrients. However, a large portion of the residues are burned in field primarily to clear the field from straw and stubble after the harvest of the preceding crop. The problem is severe in irrigated agriculture, particularly in the mechanized rice-wheat system. The main reasons for burning crop residues in field include unavailability of labour, high cost in removing the residues and use of combines in rice-wheat cropping system, especially in the Indo-Gangetic plains.

Crop waste burning is popular in NW India (Punjab, Haryana, Uttarakhand and western UP), where rice-wheat crops are harvested and threshed mechanically. Nowadays, crop waste burning is spreading throughout the country with popularization of use of combine in rice-wheat cropping system. 30–40 years back, animals were an integral part of a farmer’s family, and all crop wastes were used as feed to animal. Every household was having one compost pit in which farmers were used to decompose organic wastes along with cow dung, but with mechanization in agriculture activities, viz. ploughing, harvesting and sowing, compost pits have disappeared in the past few years. Population of animals has decreased significantly in villages. Therefore, use of crop wastes as feed of animals has decreased significantly. According to a conservative estimation, around 34 million tonnes of crop wastes are produced in Haryana, Punjab, Uttarakhand and western Uttar Pradesh. 23 million tonnes of crop wastes are burnt annually. Punjab burns 80% of crop wastes produced. This huge quantity of wastes can be converted into nutrient-rich compost for sustainable land restoration practices. Estimation showed that 30–35% of applied N&P and 70–80% of K remained in the residues of crops. Such nutrient-rich crop residues required to be converted into compost (Ram 2020).

7.3 On-Farm Production of Organic Inputs

7.3.1 Compost

The term ‘organic matter’ is used to describe the dead and decomposing remains of living things, such as plant debris, animal remains and manures. These are crucial parts of the soil, providing food for soil-living creatures, for plants in particular.

Without it, soil would be just sterile rock dust. Organic matter is continually being broken down by soil creatures and by natural oxidation. In nature, it is replenished in the natural cycles of life and death. Humus is the final product in the breakdown of organic matter. It acts as a valuable reservoir of water and plant nutrients and helps soil structure.

Crop waste burning is one of the common practices in today's farming system in India. These organic wastes can easily be converted into rich composts, viz. biodynamic, NADEP and vermi compost, to improve soil fertility. A brief account of these composts is given below:

7.3.2 Biodynamic Compost

Biodynamic compost is an effective soil conditioner and is an immediate source of nutrients for crops. It can be prepared by using green (nitrogenous material) and dry leaves (carbonaceous material) in 40–60 ratio. Integration of cow dung slurry and BD-502-507 in the compost enhances the decomposition process. The composition of air, moisture and warmth is very important in the breakdown and decomposition of organic materials. The enrich compost gets ready in 3–4 months depending upon the prevailing temperature and moisture (Fig. 7.1) (Ram 2018).

7.3.3 Vermi Compost

Earthworms are versatile natural bioreactors for effective recycling of non-toxic organic wastes to the soil. They effectively harness the beneficial soil microflora, reduce soil pathogens and convert organic wastes into valuable products such as bio-fertilizers, bio-pesticides, vitamins, enzymes, antibiotics, growth hormones and proteinous biomass. Vermi compost can easily be produced with the use of cattle dung and locally available biomass (Fig. 7.2). If vermi beds are provided a little slope, say 5–10%, then vermi wash can also be obtained without any expenditure (Ram and Pathak 2019).

7.3.4 NADEP Compost

A 2 × 3.30 × 1.25 m brick aerobic structure is constructed at an elevated place in the farm area, and organic wastes, cow dung and fertile soil are placed in the structure layer-wise. After filling of organic wastes 1.5 ft above the structure, the heap is pasted with cow dung and mud (Ram and Pathak 2016). Due to incorporation of fertile soil, proper ratio of green and dry biomass and aerobic composting process, nutritional status of end product is better than the farmyard manure. Farm wastes (cow dung, green/dry grasses, wheat/paddy straw and weeds) along with good-quality farm soils are used in composting (Fig. 7.3) (Ram 2018).

Fig. 7.1 Biodynamic compost

Fig. 7.2 Vermi compost beds, earthworms and ready vermi compost

Fig. 7.3 NADEP compost

7.3.5 Microbe-Mediated Compost

An effective microorganism consortium was developed by Prof. Teruo Higa during early 1980 in Japan. Effective microorganism is a group of beneficial microbes that act as microbial inoculants in the soil as well as develop a congenial environment for plants. It contains lactic acid and photosynthetic bacteria, yeast, filamentous fungi, actinomycetes, etc. These are aerobic and anaerobic in nature and can exist in both acidic and saline soil. These effective microbes are used for the production of good-quality compost with dung and farm wastes (Fig. 7.4).

A number of composting methods have been standardized in various parts of the country. Any of this can be attempted as per facilities available at the farm (Ram and Pathak 2016). These composts contain more nutrients than common farmyard manure (Table 7.1).

7.3.6 Bio-Enhancers

Vrikshayurveda (science of plant life) deals with growing and nourishing plants with liquid manures (prepared with plant and animal products). There are several verses (e.g. Brihat Samhita of Varaha Mihira, Surapala's Vrikshayurveda and Upavana Vinoda of Sharangadhara), which provide information on irrigation methods using water mixed with herbal products obtained from different plant species and animal

Fig. 7.4 Microbe-mediated compost

Table 7.1 Nutrient analysis (% on dry weight basis) of different compost

S. no.	Compost	N (%)	P (%)	K (%)	Ca (%)	Zn (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)
1	Vermi compost	2.15	1.29	0.53	1.72	168	61	3545	252
2	BD compost	1.68	0.17	1.23	1.20	96	45	357	3352
3	NADEP compost	0.98	0.35	1.00	1.25	162	56	430	230
4	Microbe-mediated compost	1.54	0.51	1.06	1.35	140	45	433	275
5	Farmyard manure	0.70	0.19	0.37	0.24	75	34	222	235

products to increase crop production (Sadhale 1996). Kunapajala is a combination of two words 'Kunapa' which means dead or decaying matter and 'Jala' which means water derived from this dead matter according to Sanskrit dictionaries. Kunapajala generally promotes flowering, fruiting and vegetative growth and is also used for plant protection measures (Majumdar 1935). Preparation of *Kunapajala* which involves boiling of flesh, fat and marrow of animals such as deer, pig, fish, sheep and goat in water; placing it in earthen pot; and adding milk, powders of sesame oil cake, black gram boiled in honey, decoction of pulses, ghee and hot water used to be the common booster of plant vigour (Nene 2007). *Kunapajala* is sprayed on the plant to enhance its vigour and production. Research explanation and supporting data on the implication of *Kunapajala* are not available to support their use in the present scenario. In a study, Sarkar et al. (2014) have reported that Panchagavya and Kunapajala individually as well as in combination have proved their efficacy in promoting the growth and yield of vegetable crops. Degree of efficiency of individual treatments varied, but Panchagavya with Kunapajala was found to be the best in better utilization of leaf nitrogen, efficient photosynthetic activity and improving the yield (Ram and Pathak 2017). Preparation of Kunapajala is a bit complex, and hence the other preparations which are easy to prepare and are being used by a large number of farmers have been discussed below:

Concentrated manures and bio-products in powder or in liquid form, henceforth termed as bio-enhancers, are organic preparations, obtained by active fermentation of animal and plant residues over a specific duration (Pathak and Ram 2013). These are rich source of microbial consortia, macro- and micronutrients and plant growth-promoting substances, including immunity enhancers. These are utilized to treat seeds/seedlings; enhance decomposition of organic materials, thereby enriching soil; and induce better plant vigour. These could be a potent tool to utilize in fertigation in various crops (Pathak and Ram 2012).

7.3.7 Characteristics of Bio-Enhancers

- Potent source for macro- and micronutrients
- Presence of plant growth-promoting factors
- Immunity enhancer
- Pesticide and fungicidal property
- Efficacy is influenced by inputs used and method of preparation
- Used for seed/seedling treatment, enhancing decomposition and improving soil fertility and productivity
- An effective and potent tool for fertigation

7.3.7.1 Cow Dung

The use of cow dung has been indicated since the time of Kautilya (C. 300 BC), and it has been used for dressing seeds, plastering cut ends of vegetative propagated sugar cane, dressing of wounds and sprinkling of diluted solution on crops since ancient times (Ram and Pathak 2017). ICAR-Central Institute for Subtropical

Table 7.2 Microbial population in fresh cow dung

S. no.	Type of microbes	Population (cfu/g)
1.	Actinomycetes	3.96×10^6
2.	*Azotobacter*	3.48×10^5
3.	*Azospirillum*	1.43×10^5
4.	Rhizobium	7.5×10^8
5.	Pseudomonas	1.44×10^8
6.	Phosphate-solubilizing microbes	1.9×10^8

Horticulture, Lucknow, India, has identified the presence of four potent strains of *Bacillus subtilis*, which have shown strong anti-pathogenicity against a number of diseases in fruits like mango, guava and papaya rots (Pathak and Ram 2009). Microbial analysis of fresh cow dung showed that it contains nitrogen-fixing, phosphorus-solubilizing bacteria and other beneficial microbes in plenty (Table 7.2) (Ram et al. 2017a, b).

7.3.7.2 Cow Urine

The use of cow urine has been known for a long time in India. *Gaw-mutra* (cow's urine) has been described as a liquid with innumerable therapeutic values, capable of curing several incurable diseases in human beings and plants. Cow urine is used for the preparation of a number of bio-enhancers and bio-pesticides, which are effective in improving soil fertility, quick decomposition of organic wastes and management of a large number of pests and diseases in varied group of crops (Ram and Pathak 2016).

7.3.7.3 Cow Horn Manure (BD-500)

It is basically fermented cow dung and is the basis for soil fertility and renewal of degraded soils. Fresh cow dung filled in cow horn is buried in humus-rich soil by integrating cosmic energies for a specific period (Fig. 7.5). These are buried in September–October and taken out in March–April. It is usually the first preparation used during the changeover to biodynamic farming. It is a fundamental biodynamic field spray preparation (Ram et al. 2018a, b).

Specially prepared manure is applied to enhance seed germination, root formation and development. If possible, it should be sprayed four times in a year. The best times are in autumn (October) and again in the spring (February and March). For spraying, 25 g of BD-500 is dissolved in 13.5 L of water in a plastic bucket by making vortex in clockwise and anticlockwise movement for 1 h in the evening. Spraying of BD-500 is done at the time of field preparation in the evening during the descending period of the Moon. Microbial analysis of BD-500 showed that it contains beneficial microbes responsible for improving soil fertility (Table 7.3).

7.3.7.4 BD-501

BD-501 is prepared by incubating silica powder in cow horn during April–October in the ascending period of the Moon (Fig. 7.6). It works on the photosynthetic

Fig. 7.5 Preparation of BD-500

Table 7.3 Isolation of microbes from BD-500

S. no.	Type of microbe	Microbial population (cfu/g)
1.	Actinomycetes	22.6×10^6
2.	*Pseudomonas*	0.7×10^6
3.	p-Solubilizing microbes	38.6×10^5
4.	*Azotobacter*	33.2×10^5
5.	*Azospirillum*	53.7×10^5
6.	Rhizobium	6.0×10^7

Fig. 7.6 Preparation of BD-501

process in the leaf by enhancing chlorophyll content. It strengthens the plant, improves the quality of plant produce and encourages the development of fruits and seeds. For maximum effect, BD-501 should be applied once at the beginning of a plant's life, at the four-leaf stage and again at the flowering stage or fruit maturation stage. BD-501 should be applied on the leaves in the form of fine 'mist' during morning at sunrise, and the best constellation is when the Moon is opposite to Saturn. Spraying of BD-501 has significantly improved the fruit quality of mango (Pandey et al. 2003). Microbes isolated from cow horn silica (BD-501) (Ram and Pathak 2017) are presented in Table 7.4.

7.3.7.5 Cow Pat Pit (CPP)

It is a special biodynamic field preparation and also called as 'soil shampoo'. Fresh cow dung collected from lactating and pasture-going cows is used for preparation. Cow dung is fermented along with crushed eggshells (calcium) and basalt/bentonite (clay) dust duly mixed and placed in a pit size of $3 \times 2 \times 1.5'$ (Fig. 7.7). Two sets of BD-502-507 preparations are incorporated for catalysing the composting process. It

Table 7.4 Microbial analysis of BD-501

S. no.	Type of microbes	Microbial population (cfu/g)
1.	Actinomycetes	3.3×10^6
2.	*Pseudomonas*	4.9×10^6
3.	p-Solubilizing microbes	24.2×10^5
4.	*Azotobacter*	49.0×10^5
5.	*Azospirillum*	0.7×10^5
6.	Rhizobium	6.0×10^7

Fig. 7.7 Preparation of cow pat pit

is a concentrated source of beneficial organisms. In a study, CPP showed the highest bacterial load (4.8×10^6) per g, in addition to *Rhizobium* (1.9×10^6), *Azospirillum* (0.2×10^6), *Azotobacter* (8.0×10^5) and fungi (2.5×10^6) (Ram et al. 2020). It also contained the highest amount of *B. subtilis* (1.9×10^6) responsible for disease tolerance (Proctor 2008). Microbes isolated from the cow pat pit are presented in Table 7.5.

7.3.8 Biodynamic Liquid Manure/Pesticide

Biodynamic liquid manure/pesticides are prepared by certain materials, i.e. cow dung and urine, leaves of leguminous tree, neem leaves, fish waste, castor leaves and other medicinal plant parts. Besides cow dung, cow urine and one set of BD preparations (502–507) are also incorporated. The liquid manures are used to promote the vigour and quality production (Fig. 7.8). On an average, preparation of liquid manure takes 8–10 days. In an experiment, mango hopper management with biodynamic liquid pesticides was effectively done. Before spray, the hopper population was 3.07 hoppers panicle^{-1}, and after spray, the reduction in the hopper population was found up to 15th SMW (Standard Meteorological Week) with 0.95 hoppers panicle^{-1}. Second spray was taken up at 14th SMW; as a result, hopper population reduced to 0.4 hoppers panicle^{-1} up to 19th SMW (Ram et al. 2017a, b).

Table 7.5 Microbial load of cow pat pit

S. no.	Type of microbe	Microbial population (cfu/g)
1.	Actinomycetes	13.1×10^6
2.	Pseudomonas	6.8×10^6
3.	Phosphate-solubilizing microbes	8.4×10^5
4.	*Azotobacter*	28.6×10^5
5.	*Azospirillum*	224.0×10^5
6.	*Rhizobium*	310.0×10^7

Fig. 7.8 Preparation of biodynamic liquid pesticide

7.4 Panchagavya

This preparation is rich in nutrients, auxins, gibberellins and microbial fauna and acts as a tonic to enrich the soil to induce plant vigour with quality production. It is prepared with five cow products (cow dung, cow urine, cow milk, cow ghee, cow milk curd) along with banana, coconut water and palm wine (Fig. 7.9). It gets ready in 18 days. Panchagavya is equally effective for all types of plants, milch animals, goat, poultry, fish and pet animals. Its remarkable effects have been demonstrated in fruits like mango, guava, acid lime, banana, turmeric, jasmine flower and vegetables such as cucumber and spinach. The spray of Panchagavya on chillies produces dark green-coloured leaves within 10 days, and its role has been reported by Sreenivasa et al. (2009). The effective microorganisms in Panchagavya are the mixed culture of naturally occurring, beneficial microbes, mostly lactic acid bacteria (*Lactobacillus*), yeast (*Saccharomyces*), actinomycetes (*Streptomyces*), photosynthetic bacteria (*Rhodopseudomonas*) and certain fungi (*Aspergillus*). In view of the fact that Panchagavya contains naturally occurring beneficial microorganisms (Swaminathan 2005), some of which are nitrogen fixers and P-solubilizers (Sreenivasa et al. 2011), it can be considered as an ideal organic growth promoter. However, it is advisable to use within 30 days of its preparation to achieve a better effect (Patnaik et al. 2012). Application of Panchagavya has been found more profitable than the recommended

Fig. 7.9 Preparation of Panchagavya

dose of fertilizer and agrochemical spray. In another study, it was found that among the different treatments tested against the management of insect pest in teak (*Tectona grandis*), 7% and 5% diluted Panchagavya applications were found to be more effective in controlling the pests. Cost-effective analysis showed that 7% diluted Panchagavya was found to be cheaper and affordable to tree growers.

Systematic microbial analysis of Panchagavya from 0 to 25 days suggests that Panchagavya contains maximum microbial load on the 18th day of preparation. Therefore, use of Panchagavya on the 18th day will be more effective than other days (Ram et al. 2017a, b) (Table 7.6).

7.4.1 Jeevamrita

Jeevamrita is prepared by fermenting 10 kg cow dung, 5 L urine, 2 kg jaggery, 2 kg pulse flour, 100 g virgin soil and 200 L of water by simple facilities created at the farm with minimum expenditure (Fig. 7.10). Credit for development of recipes for Jeevamrita and its extensive use goes to Palekar (2006). It can be used at 15–30-day interval through irrigation water coupled with mulching (green/dry {monocot +

Table 7.6 Different microbial populations in *Panchagavya*

S. no.	Type of microbe	Multiplication factor	Microbial population (cfu/mL) after days of preparation							
			0	3	6	9	14	18	20	25
1.	Actinomycetes	10^6	0.19	0.30	1.70	1.80	1.40	2.20	8.00	7
2.	*Pseudomonas*	10^6	1.89	1.20	1.42	2.40	6.00	47.0	57	3.1
3.	Rhizobium	10^6	1.48	6.74	1.55	2.05	1.92	2.43	4.14	2.42
4.	p-Solubilizing microbes	10^6	0.29	0.15	0.15	0.16	1.40	3.20	2.42	2.13
5.	*Azotobacter*	10^6	4.50	3.93	0.01	0.09	0.07	0.14	0.15	0.15
6.	*Azospirillum*	10^5	1.12	0.29	0.06	0.49	0.72	1.03	1.60	4

Fig. 7.10 Preparation of Jeevamrita

Table 7.7 Different microbial populations in *Jeevamrita*

S. no.	Type of microbe	Multiplication factor	Microbial population (cfu/mL) after days of preparation					
			0	3	6	9	14	20
1.	Actinomycetes	10^6	2.70	8.00	3.10	3.10	0.50	0.30
2.	*Pseudomonas*	10^7	0.19	2.60	2.89	5.09	0.005	0.30
3.	Rhizobium	10^6	1.66	10.80	12.41	75.10	35.0	0.71
4.	p-Solubilizing microbes	10^6	1.20	3.80	3.94	5.04	1.40	0.03
5.	*Azotobacter*	10^5	5.00	0.10	0.30	1.12	0.30	0.10
6.	*Azospirillum*	10^5	9.00	0.50	0.60	0.01	Nil	Nil

dicot}) and proper soil aeration. Jeevamrita is a rich source of beneficial microbes (Ram et al. 2018a, b). Systematic microbial analysis of Jeevamrita from the 0 to 20th days of preparation suggests that formulation should be used within 6–9 days for maximum benefits (Ram et al. 2017a, b) (Table 7.7). It can be drenched on mulch either by drip irrigation or through spraying. It is also effective in quick decomposition of crop residues if applied with irrigation water given for field preparation. With micro-irrigation, 3–4 times more area can be covered with 200 L of Jeevamrita.

7.4.2 Beejamrita

It is a special bio-enhancer prepared with locally available materials for seed and seedling treatment. As its preparation is very cheap and cost effective, it can easily be prepared and used by small and marginal farmers. It is prepared using 5 kg cow dung, 5 L cow urine, 50 g virgin soil, 50 g slacked lime and 20 L water (Fig. 7.11) that contains naturally occurring beneficial microorganisms (Table 7.8). It is advisable to prefer earthen/mud pot of suitable size for the preparation. It is advisable to prepare fresh *Beejamrita* and use it for treatment of seeds/seedlings and other plant parts before sowing/planting/transplanting. Microbial analysis of Beejamrita showed that it should be used on the seventh day of preparation. In case the crop is transplanted, it is advisable that seeds are treated with *Beejamrita* before sowing and while planting the root a portion of the seedlings is dipped before transplanting (Ram and Pathak 2017).

Fig. 7.11 Preparation of Beejamrita

Table 7.8 Different microbial populations in Beejamrita

S. no.	Type of microbe	Population at seventh day of preparation (cfu/mL)
3.	Actinomycetes	15.25×10^6
4.	Pseudomonas	28.32×10^6
5.	*Azotobacter*	78.98×10^6
6.	*Azospirillum*	44.93×10^5
7.	Phosphate-solubilizing bacteria	1.36×10^6
8.	Rhizobium	17.72×10^6

7.5 Amritpani

It is a special bio-formulation, rich in nutrients and beneficial microbes. Ingredients for preparation of Amritpani (Tables 7.9 and 7.10) and its intensive use were advocated by Deshpande (2003). It is used to improve seed germination, soil fertility and plant vigour. Systematic microbial analysis of Amritpani from 0 to 20 days suggests that Amritpani should be utilized from 6th to 9th days of preparation for maximum effectiveness (Fig. 7.12). After application in soil, it improves humus content, and soil organisms' activities lead to soil fertility and crop productivity (Ram and Pathak 2017).

Table 7.9 Materials required for preparation of Amritpani

S. no.	Ingredients	Quantity
1.	Cow dung	10 kg
2.	Cow ghee	250 g
3.	Honey	500 g
4.	Water	200 L

Table 7.10 Different microbial populations in *Amritpani*

Sl. no.	Type of microbe	Multiplication factor	Microbial population (cfu/mL) after days of preparation					
			0	3	6	9	14	20
1.	Actinomycetes	10^7	0.66	0.73	0.10	1.31	0.37	2.00
2.	*Pseudomonas*	10^7	0.71	1.47	1.29	1.53	4.80	3.10
3.	Rhizobium	10^6	0.50	0.40	1.20	3.03	1.12	1.64
4.	p-Solubilizing microbes	10^6	0.72	2.20	3.20	4.80	2.93	2.00
5.	*Azotobacter*	10^7	2.97	0.26	0.01	0.001	0.28	0.27
6.	*Azospirillum*	10^6	2.01	0.80	0.02	Nil	0.20	0.01

Fig. 7.12 Preparation of Amritpani

7.6 Vermiwash

Vermiwash is a liquid leachate obtained by excess water to saturate the vermi composting substrate (Fig. 7.13). It is a collection of excretory products and mucus secretions of earthworm along with nutrients from the soil organic molecules. Vermiwash was found to contain an enzyme cocktail of proteases, amylases, urease and phosphatase. Microbiological study of vermiwash revealed that it contains nitrogen-fixing bacteria like *Azotobacter* spp., *Agrobacterium* spp., Rhizobium spp. and some phosphate-solubilizing bacteria (Table 7.11) (Ram and Pathak 2017). Laboratory-scale trial showed the effectiveness of vermiwash on cowpea

Fig. 7.13 Preparation of vermiwash

Table 7.11 Microbial analysis of vermiwash

S. no.	Type of microbe	Population (cfu/mL)
1.	Actinomycetes	1.04×10^6
2.	Pseudomonas	0.01×10^7
3.	Rhizobium	0.07×10^5
4.	Phosphate-solubilizing microbes	0.06×10^6
5.	Azotobacter	0.14×10^6
6.	Azospirillum	0.007×10^6

plant growth (Zambare et al. 2008). Vermiwash contains total heterotrophs, i.e. *Nitrosomonas* 10.1×10^3, *Nitrobacter* 1.12×10^3 and total fungi 1.46×10^3.

Recently, microbial study of vermiwash revealed that it contains nitrogen-fixing bacteria like *Azotobacter* sp., *Agrobacterium* sp., *Rhizobium* sp. and phosphate-solubilizing bacteria. Protease in soils helps in seed germination, while amylases help in the availability of simple carbon source for enhancement of plant vigour and productivity as well. Soil-borne microflora is essential for growth of plants because organic nitrogenous compounds and phosphorus are decomposed and mineralized by fixing and phosphate-solubilizing bacteria (Table 7.10). Presence of large number of beneficial microorganisms helps in plant growth and protects from a number of pathogens in the field. Repeated spray of vermiwash has been found effective even in the management of thrips and mites in chillies (George et al. 2007). If needed, vermiwash may be mixed with cow urine (1:1:8 ratio, vermiwash, cow urine and water) and used as foliar spray for nutrients and insect pest management.

7.7 Entrepreneurship Development with Bio-Enhancers

Entrepreneurship can be developed by on-farm production of different composts and bio-enhancers (Ram 2019). These can be easily produced with locally available materials with a simple facility. The production cost and approximate sale value are presented in Table 7.12.

7.8 Antimicrobial Property of Microbes Isolated from Bio-Enhancers

Based on biochemical tests, most potent isolates were selected for antimicrobial properties against some selected pathogens. Bacteria V11 and V12 isolated from vermiwash were tested against *Colletotrichum gloeosporioides, Ceratocystis fimbriata, Pythium aphanidermatum* and *Fusarium oxysporum*. V12 isolate suppressed the growth of all four fungus pathogens, while V11 isolate suppressed the growth of *Colletotrichum gloeosporioides* only. Microbial isolates from cow pat pit, i.e. CPP 2, suppressed the growth of *Ceratocystis fimbriata*, but the growth of CPP 8, CPP 14 and CPP 7 was inhibited by the fungus. CPP 7, 14, 2 and 8 failed to

Table 7.12 Estimated production cost and sale value of different composts and bio-enhancers

S. no.	Bio-enhancers	Production cost/kg/L (Rs.)	Approximate sale value (Rs.)/kg/L
1.	BD-500	89.30	500
2.	BD-501	100	1000
3.	Cow pat pit	10	500
4.	Panchagavya	33.22	100
5.	Jeevamrita	2.08	100
6.	Beejamrita	1.50	10
7.	Amritpani	2.16	10.00
8.	Biodynamic liquid pesticides	1.55	5.00
9.	Vermiwash	1.10	5.00
10.	Biodynamic compost	1.72	5.00
11.	Vermi compost	1.43	5.00
12.	NADEP compost	1.40	5.00

inhibit the growth of *Pythium aphanidermatum.* CPP 8 and CPP 2 isolates inhibited the growth of *Colletotrichum gloeosporioides* and *Fusarium oxysporum*, while CPP 2, 14, 7 and 8 isolates failed to inhibit the growth of *Colletotrichum gloeosporioides* and *Fusarium oxysporum*. P 8 isolates from Panchagavya successfully inhibited the growth of all selected pathogens (Ram et al. 2019). Isolates from Beejamrita, i.e. BJ 14, 23, 12 and 14, inhibited the growth of *Colletotrichum gloeosporioides* and *Fusarium oxysporum*, but BJ 12, 14 and 23 failed to inhibit the growth of *Ceratocystis fimbriata* and *Pythium aphanidermatum* (Ram et al. 2019). George et al. (2007) have also reported the effect of vermiwash spray on increase in the yield of chilli. The positive effect of vermiwash on crop growth and yield was recorded by Zambare et al. (2008). Buckerfield et al. (1999) have also reported that weekly applications of vermiwash increased the radish yield by 7.3%, and Thangavel et al. (2003) observed that both growth and yield of paddy increased with the application of vermiwash and vermicast extracts. Sayi et al. (2018) isolated Acinetobacter spp. from Panchagavya, which possesses bio-fertilizer and proteolytic property. Joseph and Sankarganesh (2011) have also reported the antifungal property of microbes isolated from *Panchagavya.* The main constituent for the preparation of Panchagavya, cow pat pit and vermiwash, and Beejamrita is cow dung. Yangabi et al. (2009) have recorded cow dung slurry effect on the antimicrobial property of medicinal crops. Swain et al. (2008) have isolated *Bacillus* subtilis from cow dung, which is used as a bio-control agent in several cases. Waziri and Suleiman (2013) also reported the antimicrobial property of cow dung vapour against pathogens. Proctor (2008) has suggested seed/seedling treatment with cow pat pit for the management of soil-borne disease. In another study, Utpal et al. (2013) have reported that Panchagavya resulted in 86.30% inhibition of mycelial growth and 95.9% of spore germination of *Curvularia lunata*. They have concluded that Neemazole, Trichoderma and Jeevamrita (prepared with cow dung) can be used to manage *P. sorghi* instead of fungicides, which will be the cheapest and eco-friendly way to manage the common rust of maize. Seed treatment with Panchagavya further enhanced the seed germination with 90.7% and vigour index of 1036. Its regular use of 3% solution has been found very effective in a large number of crop pests and diseases such as leaf spot, blight, mildew and rust of vegetables (Nagaraj and Sreenivasa 2009).

7.9 Kitchen Waste Management

7.9.1 Reduction in Municipal Solid Wastes, Improving Happiness and Organic Food Security at Rooftop

The world generates 4.7 million metric tonnes of wastes daily, and India contributes to 0.4 million metric tonnes daily. By 2050, 1750 acres of land will be required for dumping of these municipal wastes. Delhi, Mumbai, Chennai, Hyderabad and Kolkata are the top five cities which generate maximum wastes in India. Dumping and burning of municipal organic wastes at the outskirt of any city generate CO_2, N_2O, polycyclic hydrocarbons and mercury, which pollute air and water and cause several respiratory problems to animals and human beings (Kumari et al. 2019).

7.9.2 Viable Solutions

Kitchen and other organic wastes generated in every household can be used for growing of vegetables and fruits at rooftop to grow pesticide-free food. Two bio-digesters (containers) are required and can be placed at the rooftop for decomposition of kitchen wastes. After complete filling of one container, any bio-enhancers, viz. Amritpani, Jeevamrita or cow pat pit, may be added for fast smell-free decomposition of wastes. Second container will be used for filling of kitchen wastes, after complete filling of the first container. First container's wastes are converted into good-quality compost till the complete filling of second container. This process will be continued throughout the year.

Ready compost can be used as potting mixture along with soil for filling of the structure/pots. Crop wastes generated by growing of different vegetables can also be used as mulching in the structure/pots. Normally, insect pest occurrence at rooftop in vegetables is negligible, but any incidence of insect pest can be managed by 3% neem oil spray.

7.9.2.1 Precautions

1. Sowing/planting of open pollinated varieties is recommended.
2. Conversion of kitchen wastes into compost should be continued throughout the year.
3. Use of bio-enhancers will ensure fast conversion of wastes into good-quality compost as well as plant growth and development.

4. Refrain from the use of any agrochemicals in rooftop garden.
5. Mulching is an integral part of rooftop garden.
6. If possible, a structure may be made for climbing vegetables.

7.9.3 Rooftop/Terrace Gardening

Kitchen and other bio-wastes generated in every household can be used for growing vegetables, few select herbs, and ornamental plants including few fruits at the rooftop and other terrace without fertilizers and pesticides. For this, dry and wet bio-wastes which are available in routine should be utilized. Dry waste may include dry leaves, lawn clippings, saw dust, coconut husk, cardboard pieces, etc. and wet includes vegetable and fruit peels and other bio-materials. Two containers of appropriate size may be earthen, plastic or cement, which could be used as a bio-digester for regular decomposition of these materials. These should be placed at the top of the terrace for routine decomposition of bio-waste to convert as rich manure. Daily wastes which are generated should be filled in one container; after filling, say, up to 3/4th, it should be drenched with any bio-enhancer such as Jeevamrita/cow pat pit/Agnihotra ash water/vermiwash as per the convenience for enhancing decomposition of materials. Normally, it takes a few days for decomposition. The other container should be used for filling. This should be a routine process for regular cleaning of household and availability of enriched compost. Ready compost along with some garden soil from nearby area should be used as the filling mixture in any structure or container or structure which can be used for the production of daily requirements. One should try to procure seeds or seedlings on their own or try to procure from nearby genuine source for growing as per season. Regular collection and use of crop waste, generated in routine, or those which can be obtained from dropping of foliage from nearby trees and lawns or from nearby fruit and vegetable markets should be placed in gaps as mulching material. Mulching and its drenching with bio-enhancer will help for quality production. After thorough filtrations, bioenhancers can be used as foliar spray. In general, there is minimum possibility of insect pest occurence, but in case of incidence, simple practices such as use of light trap/pheromone trap/cow urine and cow butter milk or neem oil can be used (Ram 2020).

7.9.3.1 Precautions

- Conservation of kitchen waste and other waste should be a regular practice rather than throwing in the garbage.
- Decomposition of these materials in a container or as mulch should be inculcated as a hobby.
- Mulching is an integral part of rooftop garden.
- If possible, a structure may be made for climbing vegetables/fruits/ornamental plants.

- Regular use of bio-enhancers for quick decomposition of materials filled in bio-digester or those mulched in gaps of the crop will enhance quality production in all crops grown.

In fact, rooftop/terrace production of few selected horticultural crops is a source of physical exercise, management of kitchen wastes and pesticide-free food for family members as shown in Figs. 7.14, 7.15 and 7.16.

It appears to be simple but has many implications such as regular supply of quality produce and high esteem of family members, particularly children and old persons in the family. By this gesture, one can help in cleaning the home and nearby area and help in minimizing air pollution. As an example, one can look at a few pertinent photographs.

A few agencies have developed Portable Rooftop Farming Systems—these can be installed directly on rooftops and fresh organic crops can be grown.

Fig. 7.14 Containers for decomposition of kitchen wastes and use of compost in growing of vegetable crops

Fig. 7.15 Rooftop vegetables production with kitchen waste utilization

Fig. 7.16 Vegetables harvest at rooftop

- Besides these efforts, there are some climbing plants such as gourds, pole beans, grape and passion fruit, which can be trained to grow along the height of the building, spread at the top of it.
- The other alternative is to grow vine vegetables in suitable structures at balconies and train downward for bearing the fruits. It is important to mention that there is regular dropping of older leaves; these need to be collected and utilized as mulch materials or for preparation of vermicompost.

Crops like chillies, coriander, basil, few cucurbits and some vegetables, which have a tendency of bearing over longer duration, are preferred. It is customary to have a small structure at rooftop/balcony for climbing vegetables such as sponge gourd, snake gourd, bottle gourd, bitter gourd, pointed gourd and climbing beans can be trained on these structures to get some home-grown vegetables.

7.9.4 Advantage of Rooftop/Terrace Gardening

- Rooftop/terrace gardening is a pleasant hobby to every person, particularly aged people and growing children.
- Just like senior citizens, it provides equal opportunity to children to gain self-confidence of creating some positive contribution.
- It gives inner joy to keep watch on different stages of plants taking place right from germination to growth, flowering, fruiting and harvesting.
- It provides ample opportunity for fruitful utilization of time.
- Harvesting of fresh produce for daily consumption provides immense satisfaction, which cannot be measured in financial terms.

7.10 Conclusion

From the above enumeration, it can be concluded that on-farm-produced inputs could be a potent source of nutrients and beneficial microbes to improve soil fertility, crop productivity and produce quality. Bio-enhancers could be a potential alternative for fertigation, which is becoming common in most of the crops. But it should be noted that bio-enhancers which are used in limited quantities cannot meet the entire nutrient requirement of the crops. These simply catalyse quick decomposition of organic wastes into humus; hence, incorporation of enough biomass, preferably combination of monocot and legumes duly supplemented with animal wastes, will be helpful in quality production of humus which is a prerequisite for improving soil fertility and crop productivity. Combination of manures and frequent use of bio-enhancers and bio-pesticides can address many challenges of horticulture production and will be helpful to show a way for sustainable production through organic resources.

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Bitter Gourd for Human Health, Nutrition, and Value Addition

8

Gograj Singh Jat, Tusar Kanti Behera, and Umesh K. Reddy

Abstract

Bitter gourd has been traditionally used in Ayurvedic and Chinese medicine in many Asian countries. It is ranked first among cucurbits for its higher nutritive values like carbohydrates, vitamins, proteins, minerals, and phytochemicals. More than 60 phytonutrients have been reported in bitter gourd, which are used to treat deadly diseases, mainly diabetes, cancer, and inflammation-associated problems. Bitter gourd fruits possess several medicinal and health-promoting properties such as antimutagenic, antiviral, antiulcerogenic, antitumor, anti-lipolytic, and hypoglycemic activities. The medicinal property of bitter gourd includes its high antioxidant activities due to the presence of phenols, flavonoids, isoflavones, glucosinolates, terpenes, anthraquinones, gallic acid, and caffeic acid, which can serve as an alternate to replace the synthetic antioxidants for improving food quality. The α- and β-momorcharin proteins of bitter gourd fruits have an inhibitory effect against the human immunodeficiency virus (HIV). A series of processed products can enhance its consumption including juice, chips, rings, pickles, etc. which are healthier and palatable than raw fruits. In this chapter, nutritional value, medicinal importance, health-promoting phytochemicals of bitter gourd, and their mode of action are discussed in detail. This chapter would be helpful for consumers and producers to update themselves with current knowledge on bitter gourd for nutrition and health and for policymakers and researchers/bitter gourd geneticists and breeders to prepare a

G. S. Jat
Division of Vegetable Science, ICAR-Indian Agricultural Research Institute, New Delhi, India

T. K. Behera (✉)
ICAR-Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh, India

U. K. Reddy
Department of Biology, West Virginia State University, Institute, WV, USA

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future road map of bitter gourd for enhancing phytochemicals and nutritional quality of the fruits.

Keywords

Momordica charantia · Nutrition · Value addition · Medicinal value · Antidiabetic

8.1 Introduction

Vegetables are considered protective food and play a significant role in human nutrition as a source of vitamins (vitamins A, B, C, and E; thiamine; and niacin), minerals (K, Ca, P, Fe, Zn, Mn, etc.), dietary fiber, phytonutrients (Quebedeaux and Eisa 1990; Wargovich 2000; Perera et al. 2021), nutraceutical value (lycopene, anthocyanin, carotenoids, capsanthin, capsaicin, chlorophyll, glucosinolates, indole-3-carbinol, sulfur compounds, isothiocyanate, charantin, momordicine, citrulline, etc.), and bioactive compounds (ascorbic acid, phenolic acid, carotenoids, flavonoids) (Cefalu et al. 2008; Patel et al. 2019; Akyuz et al. 2020; Venugopal and Dhanasekaran 2020; Perera et al. 2021). These compounds are beneficial in reducing the incidence of deadly diseases like cancer, cardiovascular disease, diabetes, and chronic diseases (Quebedeaux and Eisa 1990; Wargovich 2000; Shivanagoudra et al. 2019; Perera et al. 2021) and gout, jaundice, rheumatism, and pneumonia (Joseph and Jini 2013). Among vegetables, bitter gourd or bitter melon/*karela* (*Momordica charantia* L.), also known as the gold mine of functional bioactive compounds, is one of the important health-promoting and nature's most bountiful gifted vegetable crop belonging to the family Cucurbitaceae. Bitter gourd is commercially cultivated on large scale in tropical regions such as India, Malaysia, China, Africa, and the Middle East (Pehlivan 2021; Rathod et al. 2021a; Gayathry and John 2022). Every plant part of bitter gourd (fruit, seed, leaves, stem, roots, etc.) has been used as a remedy for all kinds of diabetes (Abascal and Yarnell 2005; Islam et al. 2011; Raoof and Mohamed 2018; Shivanagoudra et al. 2019; Rathod et al. 2021b). The traditional uses of bitter gourd in folk medicines (Polito et al. 2016) revealed that it is one of the most important plants for lowering blood glucose levels in diabetic patients (Paul and Raychaudhuri 2010; Perera et al. 2021; Pehlivan 2021; Gayathry and John 2022). Due to its several medicinal properties, it is highly preferred by consumers in the form of either culinary preparation, juice, or value-added products (Thakur and Sharma 2016). The immature fruits can be used as fried, deep-fried, juiced, pickled, and boiled and can be dried to drink as tea (Myojin et al. 2008; Gayathry and John 2022). The fat content in fruit ranges from 2.9 to 6.4% of total dry matter content (Chuang et al. 2006; Habicht et al. 2011). However, due to its high nutrient content and therapeutic values (Pal et al. 2005; Perera et al. 2021), there is high demand in the market for bitter gourd fruits; therefore, the area of bitter gourd crop is increasing, particularly in Asian and European countries and California and Florida states of the United States. This review will concentrate on nutritional as well as functional bioactive health compounds of bitter gourd, the mode of action of these bioactive compounds for medicinal properties, and important value-added products of bitter gourd.

8.2 Bitter Gourd Plant

Bitter gourd is a monoecious (both male and female flowers borne on the same plant but in different positions), annual, tendril, climbing vine. The plant bears yellow-colored flowers. Bitter gourd fruits are available in the market in different fruit colors (dark green, light green, and white), shapes, and sizes (small, medium, long, and extra-long (Fig. 8.1; Table 8.1) depending on consumer preferences (Behera et al. 2006; Rathod et al. 2018, 2021a; Alhariri et al. 2018; Rao et al. 2022). Fruits turn orange color while ripening. Bitter gourd germplasm possesses high level of diversity for several morphological traits, sex form (gynoecious, predominantly gynoecious, and monoecious), and fruit traits (Behera et al. 2010, 2020; Rao et al.

Fig. 8.1 Diversity for fruit (size, shape, color, surface texture) characters in *Momordica charantia* L., *** *M. balsamina*, a wild species of bitter gourd

Table 8.1 Botanical classification of *Momordica charantia* L.

Common name	Bitter gourd/bitter melon/karela
Kingdom	Plantae
Order	Cucurbitales
Species	*M. charantia*
Genus	*Momordica*
Family	Cucurbitaceae
Class	Magnoliopsida
Division	Magnoliophyta

2018; Alhariri et al. 2020, 2021). Genetic diversity was also observed for the phytochemical composition in bitter gourd flesh, and this variation may be due to genotype, climatic conditions, and agricultural practices (Kumari et al. 2017). Indian bitter gourd (*Momordica charantia* var. *charantia*) bears large fusiform fruits, while *Momordica charantia* var. *muricata*, a wild species, develops small, rounded fruits with a spiny surface (Chakravarty 1990; Rathod et al. 2019, 2021a, b). In China, three distinct types occur, small-fruited (10–12 cm, extremely bitter fruits), long-fruited (30–60 cm, slightly bitter), and medium- to long-fruited genotypes (8–10 cm, triangular or cone-shaped fruits with moderate-to-strong bitterness, Alhariri et al. 2021). The seeds are 10–15 mm long, straw color, covered with flesh, white in unripe fruits, and red in ripened fruits (Poolperm and Jiraungkoorskul 2017).

8.2.1 Medicinal Uses of Bitter Gourd

The bitter gourd fruit juice and beverages possess nutraceutical properties due to the presence of certain bioactive compounds (Thakur and Sharma 2016). The plant extract of bitter gourd has been traditionally used in the treatment of diabetes in countries like India and China and in Central America (Grover et al. 2002; Yeh et al. 2003; Chen et al. 2003; Raoof and Mohamed 2018; Shivanagoudra et al. 2019; Gayathry and John 2022). The several benefits of bioactive health compounds of bitter gourd include hypoglycemic (Ali et al. 1993; Srivastava et al. 1993; Jayasooriya et al. 2000; Kandangath et al. 2015; Pehlivan 2021), anticarcinogenic and hypercholesterolemic (Ganguly et al. 2000; Ahmed et al. 2001; Uebanso et al. 2007; Janagal et al. 2018), and antidotal, antipyretic, tonic, appetizing, and antibilious activities (Sandhya et al. 2000; Kandangath et al. 2015; Gayathry and John 2022) in different parts of bitter gourd plants like mesocarp, seeds, and vegetative parts that have been well documented (Table 8.2). More than 60 phytonutrients have been identified in different parts of bitter gourd plants, which are used as a remedy for approximately 30 diseases including diabetes and cancer (Kole et al. 2020). The bioactive compounds like charantin (hypoglycemic, Yeh et al. 2003), momorcharin (inactivating ribosome, Feng et al. 1990; Leung et al. 1997), MAP30 (a bitter gourd HIV protein that suppresses HIV activity, Lee-Huang et al. 1995), vicine (hypoglycemic, Dutta et al. 1981), and momordicoside A and B (inhibit tumor growth, Okabe et al. 1980; Anilakumar et al. 2015) and antimutagenic activities (Anilakumar et al. 2015) have also been documented well for their health-promoting attributes and lowering of blood glucose (Janagal et al. 2018; Gayathry and John 2022). Several other medicinal properties of bitter gourd have been characterized, attributed to a broad array of biologically active phytochemicals (Table 8.2), including triterpenes and steroids (Grover and Yadav 2004; Gayathry and John 2022). These phytochemicals possess several medicinal properties like antimicrobial (Omoregbe et al. 1996; Yesilada et al. 1999; Gayathry and John 2022), antiviral (Takemoto 1983; Lee-Huang 1990; Nerurkar et al. 2006: Altaf and Khan 2021; Pehlivan 2021), antifertility (Basch et al. 2003), and antiulcerogenic (Gurbuz et al. 2000). Sugar, proteins, and chlorophyll are the major primary metabolites,

Table 8.2 Phytochemicals in different parts of bitter gourd plant

Plant parts	Phytochemicals/constituents
Vegetative parts	Momorcharins, momordenol, momordicilin, momordicins, momordicinin, momordin, momordolol, charantin, chlorine, cryptoxanthin, cucurbits, cucurbitacins, cucurbitanes, cycloartenols, diosgenin, eleostearic acids, erythrodiol, galacturonic acids, gentisic acid, goyaglycosides, goyasaponins, multiflorenol. Glycosides, saponins, alkaloids, fixed oils, cucurbitane-type triterpenes, proteins, and steroids. Momordicine, charantin, polypeptide-p insulin, ascorbigen
Fruits	**Amino acids**—aspartic acid, serine, glutamic acid, threonine, glutamic acid, threonine, alanine, g-aminobutyric acid and pipecolic acid, luteolin **Cucurbitane triterpenoids—**charantin, momordicins I, II, and III; kuguacins A–S; karavilagenins A, B, C, D, and E; saponins; goyasaponins; diosgenin **Fatty acids**—lauric, myristic, palmitic, palmitoleic, stearic, oleic, linoleic, linolenic acid **Enzyme**—urease **Phytosterols**—decortinone, clerosterol, ergosterol peroxide, stigmasterol, campesterol, β-sitosterol
Seeds	Amino acids—valine, threonine, methionine, isoleucine, leucine, phenylalanine, and glutamic acid
Antidiabetic compounds (fruits)	Triterpene, proteid, steroid, alkaloid, inorganic, lipid, and phenolic compounds
Chemical constituents for health (fruits and vegetative parts)	Alkaloids, charantin, charine, cryptoxanthin, cucurbitins, cucurbitacins, cucurbitanes, cycloartenols, diosgenin, eleostearic acids, erythrodiol, galacturonic acids, gentisic acid, goyaglycosides, goyasaponins, guanylate cyclase inhibitors, gypsogenin, hydroxytryptamines, karounidiols, lanosterol, lauric acid, linoleic acid, linolenic acid, momorcharasides, momorcharins, momordenol, momordicilin, momordicin, momordicinin, momordicosides, momordin, momordolol, multiflorenol, myristic acid, nerolidol, oleanolic acid, oleic acid, oxalic acid, pentadecanes, peptides, petroselinic acid, polypeptides, proteins, ribosome-inactivating proteins, rosmarinic acid, rubixanthin, spinasterol, steroidal glycosides, stigmasta-diols, stigmasterol, taraxerol, trehalose, trypsin inhibitors, uracil, vacine, v-insulin, verbascoside, vicine, zeatin, zeatin riboside, zeaxanthin, zeinoxanthin amino acid-aspartic acid, serine, glutamic acid, thscinne, alanine, g-aminobutyric acid and pipecolic acid, ascorbigen, *b*-sitosterol-D-glucoside, citrulline, elasterol, flavochrome, lutein, lycopene, pipecolic acid, charantoside XV, karaviloside VI, karaviloside VIII, momordicoside L, momordicoside A, kuguaglycoside C

Source: Anilakumar et al. (2015) with modification while phenolics, alkaloids, carotenoids, cucurbitane triterpenoids, and saponins are secondary metabolites in bitter gourd (Gayathry and John 2022). Bitter gourd fruit is good for health even though most people avoid eating it because of its bitter taste due to the presence of the alkaloid momordicine (Harinantenaina et al. 2006; Nagarani et al. 2014) and some polyphenolic compounds. However, fruits can be used after blanching or soaking in salt water to reduce bitterness (Saeed et al. 2018).

Plant phenolics and polyphenolic compounds derived from bitter gourd fruits and seeds are the primary natural antioxidants in bitter gourd, which may serve as an alternative to replace synthetic antioxidants to improve food quality (Horax et al. 2010). The major polyphenolic compounds in bitter gourd fruits are flavonoids, coumarins, anthraquinones, and anthocyanin (Kubola and Siriamornpun 2008; Horax et al. 2010; Nagarani et al. 2014; Akyuz et al. 2020; Gayathry and John 2022). Bitter gourd fruits contain carotenoids as an antioxidant compound that protects humans from carcinogens and heart disease (Simon 1997; Patel et al. 2019). The fruit of bitter gourd contains 14 carotenoids (5 at immature stage, 6 at mature green, and 14 at ripe stage) and cryptoxanthin (a principal chloroplast and chromoplast-based pigment present at ripe stage, Rodriguez et al. 1976). Bitter gourd fruits also contain β-carotene, zeaxanthin, and lycopene (primarily at ripe stage), and lutein and α-carotene (primarily at immature stage); therefore, bitter gourd could serve as an instructive model for carotenogenesis study during ripening stage (Rodriguez et al. 1976; Tran and Roymundo 1999; Patel et al. 2019). The total carotenoid dry weight concentration of the seeds of bitter gourd at immature stage (~2.8 μg/g) is relatively low compared to the ripe stage (~271 μg/g). The presence of carotene in the ripe seed coat is exclusively lycopene (~261 μg/g), which constitutes about 96% of the total carotenoid found in seeds of ripe fruits (Rodriguez et al. 1976). The other antioxidants in plants are vitamin C, vitamin E, phenolic acids, and organosulfur compounds (Simon 1997). Bitter gourd fruits are also a good source of antioxidants like gallic acid, gentisic acid, catechin, chlorogenic acid (Budrat and Shotipruk 2009; Akyuz et al. 2020), saponins (Tan et al. 2014a, b; Akyuz et al. 2020), reducing sugars, and epicatechin that can be in the range of mg/kg each on dry weight basis among cultivars. These natural plant phenolics are an excellent source of antioxidants for reducing blood pressure, cancer, and cardiovascular disease (Tanaka et al. 1993; Balentine et al. 1997; Bravo 1998; Surh 1999; Gorinstein et al. 2002; Wang and Mazza 2002; Hannum 2004; Akyuz et al. 2020; Pehlivan 2021).

8.2.2 Nutritional Importance

Among cucurbits, bitter gourd is one of the richest sources of nutrients (Miniraj et al. 1993; Xiang et al. 2000). Bitter gourd fruit is rich in carbohydrate, proteins, vitamins, minerals (Yawalkar 1980; Grover and Yadav 2004), folic acid, thiamine, riboflavin, and niacin (Ali et al. 2008; Sandra et al. 2011; Joseph and Jini 2013; Pehlivan 2021) (Table 8.3). The vitamin C content in Chinese bitter gourd germplasm (44–78 mg/g of fresh edible weight), 16 essential amino acids, and crude

Table 8.3 Nutritional value of bitter gourd (long-fruited *M. charantia* var. *charantia* and small-fruited *M. charantia* var. *muricata*) and its comparison with cucumber (*Cucumis sativus* L.)

Fruit content[a]	Long fruited (*M. charantia* var. *charantia*)	Small fruited (*M. charantia* var. *muricata*)	*Cucumber* (*Cucumis sativus* L.)
Moisture	92.4 g	83.2 g	96.3 g
Carbohydrate	4.2 g	9.8 g	2.5 g
Protein	1.6 g	2.9 g	0.4 g
Fat	0.2 g	1.0 g	0.1 g
Fiber	0.8 g	1.7 g	0.4 g
Calcium	20.0 mg	50.0 mg	10.0 mg
Phosphorus	70.0 mg	140.0 mg	25.0 mg
Iron	2.2 mg	9.4 mg	1.5 mg
Vitamin A (carotene)	210 IU	220 IU	–
Vitamin C	70–85 mg	90–120 mg	7.0 mg

[a]Composition per 100 g fresh edible portion (Source: Behera et al. 2007)

protein (11.4–20.9 g/kg) are higher than tomato and cucumber (Xiang et al. 2000). P-insulin, a pure protein extracted from bitter gourd flesh in crystalline form, is also tested (EeShian et al. 2015; Shubha et al. 2018). Small-fruited bitter gourd, *Momordica charantia* var. *muricata*, contains higher amount of carbohydrate, protein, fat, dietary fiber (Gopalan et al. 2000), calcium, phosphorus, and iron compared to long-fruited bitter gourd genotype *Momordica charantia* var. *charantia* (Desai and Musmade 1998; Behera et al. 2006, 2007; Islam et al. 2011) (Table 8.3). A considerable amount of variation is recorded for nutrients in Indian bitter gourd germplasm. Bitter gourd is a good source of vitamin A (471 IU), potassium (296 mg), vitamin C (84 mg), phosphorus (31 mg), and iron (0.43 mg) per 100 g of fresh fruit weight (Paul and Raychaudhuri 2010). The fresh leaves are also a good source of Ca (1%), Fe (3%), K (7%), P (5%), and Mg (4%). The seed of bitter gourd is also a rich source of protein and oil (Ali et al. 2008). Seed oil is rich in stearic acid, oleic acid, and α-linoleic acid, which exhibits antidiabetic and antitumor activities (Fang and Ng 2016; Perera et al. 2021; Gayathry and John 2022). Bitter gourd is the best natural source of chromium (5.65 mg/100 g) and zinc (45.45 mg/100 g) (Saeed et al. 2018). Bitter gourd is a rich source of several amino acids such as lysine, leucine, valine, glutamine, asparagine, glycine, alanine, leucine, arginine, proline, serine, isoleucine, tryptophan, and methionine (Islam et al. 2011; Altaf and Khan 2021; Gayathry and John 2022).

8.2.3 Bioactive Compounds in Bitter Gourd for Human Health

Scientists and researchers are interested in studying the bioactive health compounds of bitter gourd and their mode of action in the human body. Bitter gourd contains 228 different compounds in different plant parts (Gayathry and John 2022). Bitter melon extract from different plant parts like leaves, fruits, stems, and seeds contains several bioactive compounds (Table 8.4) that are well known for their hypoglycemic activities in diabetic humans and animals (Wehash et al. 2012; Fuangchana et al. 2011; Joseph and Jini 2013; Shivanagoudra et al. 2019; Perera et al. 2021; Gayathry and John 2022). Two saponins isolated from bitter gourd, momordicine II and 3-hydroxycucurbita-5,24-dien-19-al-7,23-di-*O*-β-glucopyranoside, showed significant insulin-releasing activity in MIN6 β-cells at a concentration of 10 and 25 μg/mL (Keller et al. 2011). Several herbal products have been used across the world to treat hypoglycemia, and among these, bitter gourd is considered one of the popular herbal resources (Rahman et al. 2011; Pehlivan 2021). Presently, various processed forms of bitter gourd like capsules or tablets are advertised and sold in the market under the brand name of Gourdin, Karela, and Glucobetic in Canada, India, the United Kingdom, the United States, and many Asian countries. These products are also available online. The major lacuna in the marketing of these capsules is that Diabetes UK has released a warning with regard to the use of Karela capsules because what dose is safe and when taken with other antidiabetic agents is still not known, and there is a lack of information on the potential bioactive compounds of the capsules. The major bioactive compounds from bitter melon fruits having hypoglycemic activities include charantin, polypeptide-p, and vicine (Joseph and Jini 2013; Gayathry and John 2022).

Charantin It is a potential antidiabetic compound and a cucurbitane triterpenoid in bitter gourd (Krawinkel and Keding 2006; Patel et al. 2010; Shivanagoudra et al. 2019; Perera et al. 2021; Gayathry and John 2022), which contains sitosteryl glucoside and stigmasteryl glucoside which can replace diabetes treatment (Pitiphanpong et al. 2007; Raoof and Mohamed 2018). Both compounds did not produce any notable changes in blood glucose level when tested for their hypoglycemic activity in vivo (Harinantenaina et al. 2006), which indicates that charantin may contain some other specific components responsible for hypoglycemic activities in diabetics. Charantin is more effective in diabetes than the oral hypoglycemic agent tolbutamide (Cousens 2008; Shivanagoudra et al. 2019; Perera et al. 2021; Gayathry and John 2022).

Polypeptide-p Polypeptide-p is an insulin-like hypoglycemic protein. Bitter gourd contains polypeptide-p or p-insulin, which controls diabetes naturally (Hellolife 2008; Shivanagoudra et al. 2019) by lowering down the blood glucose levels in gerbils, langurs, and humans (Tayyab et al. 2012). P-insulin works by mimicking the action of human insulin in the body; therefore, p-insulin may be used as plant-based insulin replacement in patients with type 1 diabetes (Paul and Raychaudhuri 2010). Wang and Ng (2001) have cloned and expressed the 498 bp gene sequence coding for bitter gourd polypeptide-p gene.

Vicine Another important major compound isolated from bitter gourd seeds is glycol alkaloid known as vicine, which induces hypoglycemia in nondiabetic fasting rats by intraperitoneal administration (Han et al. 2008).

Table 8.4 Principal bioactive compounds of bitter gourd, their functions, and plant parts extracted

Principal bioactive compounds	Major functions	Plant parts	References
Polypeptide and proteins	RNA *N*-glycosidase, polynucleotide adenosine glycosidase (PAG), superoxide dismutase, DNase-like, phospholipase, antitumor, immune suppression, antimicrobial	Seeds, fruits	Leung et al. (1997); Paul and Raychaudhuri (2010); Fang et al. (2012a); Fang et al. (2012b); Meng et al. (2012); Jain and De (2016); Jabeen and Khanum (2017); Jia et al. (2017); Chakraborty et al. (2020); Pehlivan (2021); Gayathry and John (2022)
Polysaccharides	Antidiabetic, antioxidant, antitumor, immunity boosting, neuroprotective	All parts	Zhang et al. (2008); Cai et al. (2010); Deng et al. (2014); Xu et al. (2015); Duan et al. (2015); Zhang et al. (2016); Shivanagoudra et al. (2019); Sur and Ray (2021); Perera et al. (2021); Gayathry and John (2022)
Terpenoids	Antidiabetic, antioxidant, anticancer, cancer chemoprevention	Fruits, leaves, stem	Akihisa et al. (2007); Agrawal and Beohar (2010); Liu et al. (2010); Ullah et al. (2011); Chou et al. (2015); Ingle and Kapgatte (2018); Mahwish et al. (2018); Ummi et al. (2018); Shubha et al. (2018); Shivanagoudra et al. (2019); Yue et al. (2019); Sur et al. (2019); Altaf and Khan (2021); Perera et al. (2021); Gayathry and John (2022)
Saponins	Antiviral, antihyperglycemic, hypolipidemic	Fruits, roots, seeds	Chang et al. (2004); Xia et al. (2007); Han et al. (2008); Keller et al. (2011); Jia et al. (2017); Gayathry and John (2022)
Phenolics	Antioxidant, immunity boosting, anti-inflammation	Fruits, seeds, pericarp	Lin and Tang (2007); Ullah et al. (2011); Qader et al. (2011); Nagarani et al. (2014); Tan et al. (2014a, b); Sutanto et al. (2015); Jia et al. (2017); Ingle and Kapgatte (2018); Mahwish et al. (2018); Shivanagoudra et al. (2019); Bortolotti et al. (2019); Akyuz et al. (2020); Perez et al. (2021); Perera et al. (2021); Gayathry and John (2022)
Phytosterol	Several diseases	Fruits	Ullah et al. (2011); Kim et al. (2013); Shubha et al. (2018);

(continued)

Table 8.4 (continued)

Principal bioactive compounds	Major functions	Plant parts	References
			Ummi et al. (2018); Gayathry and John (2022)
Alkaloids		Fruits and leaves	Li et al. (2015); Shubha et al. (2018); Ingle and Kapgatte (2018); Mahwish et al. (2018); Gayathry and John (2022)
Lipids	Antitumor, antioxidant	Seeds, flesh	Suzuki et al. (2001); Tsuzuki et al. (2004); Dhar et al. (2007); Bortolotti et al. (2019)
Charantin	Antidiabetic	Fruits	Joseph and Jini (2013); Alam et al. (2015); Zaini et al. (2018); Shivanagoudra et al. (2019); Venugopal and Dhanasekaran (2020); Perera et al. (2021); Gayathry and John (2022)
Carotenoids	Antioxidants	Fruits (ripe pericarp)	Shubha et al. (2018); Patel et al. (2019); Gayathry and John (2022)

8.2.4 Health Benefits of Bitter Gourd

1. ***Hypoglycemic activity:*** The fruits of bitter gourd contain several bitter compounds like momordicine, charantin, vicine, glycosides, and karavilosides along with polypeptide-p and plant insulin, which are hypoglycemic in action (Alam et al. 2015; Gayathry and John 2022) and improve blood sugar levels by increasing glucose uptake and glycogen synthesis in the liver, muscles, and fat cells (Raman and Lau 1996; Harinantenaina et al. 2006). Bitter gourd contains lectin, which is reported to have insulin-like activity due to its linking together two insulin receptors. This lectin lowers blood glucose concentrations by acting on peripheral tissues like insulin's effects on the brain while suppressing appetite (Thakur and Sharma 2016). The oral supplement of alcoholic extracts of the plant to diabetic patients did not show any hypoglycemic action (Shubha et al. 2018).
2. ***Antioxidant properties:*** The antioxidant properties in bitter gourd fruits are due to the presence of several types of carotenoid compounds, which protect humans from carcinogens and mitigate free radical effects associated with heart disease (Patel et al. 2019). These phenolic compounds may vary with the maturity stage of fruits. In immature fruits, it ranges from 6.9 to 15.7, mature 6.4 to 14.8, and ripe 4.3 to 14.9 mg GAE/g ethanol extract, whereas in mature and ripe seeds, it ranges from 6.4 to 18 and 6.1 to 20.9 mg GAE/g ethanol extract, respectively

(Horax et al. 2010). The phenolic content in greenhouse-grown bitter gourd crop ranges from 5.1 to 7.9 mg GAE/g dry basis (Tan et al. 2014a, b).

3. ***Antifertility effects:*** Excessive consumption of the fruit and leaves of bitter gourd can reduce sperm production. Bitter gourd ethanol seed extracts have also shown to have potent male antifertility effects when administered to dogs and guinea pigs. The extract of the seed also has antispermatogenic effect (Patil and Patil 2011). Traditionally, bitter gourd juice has also been used to induce abortions. Therefore, pregnant women are advised not to use bitter gourd fruits during pregnancy (Grover and Yadav 2004).
4. ***Antiviral properties:*** In recent years, several chemical components have been isolated from bitter gourd, such as c-momorcharin, which inactivates ribosome function and stimulates MAP30 (momordica anti-HIV protein) production, which, in turn, simultaneously suppresses white spot syndrome virus and human immunodeficiency virus (HIV) activity (Lee-Huang et al. 1995). The fruit juice of bitter gourd has anti-helminthic properties, which are useful in the treatment of malarial fever (Abdullah and Kamarudin 2013; Gayathry and John 2022) and the reduction of fat (Abdullah and Kamarudin 2013; Kandangath et al. 2015).
5. ***Antimicrobial activity:*** The leaf extracts of bitter gourd possess antimicrobial activity principally against *Escherichia coli*, *Staphylococcus*, *Pseudomonas*, *Salmonella*, *Streptobacillus*, and *Streptococcus*. More specifically, fruit extracts of *M. charantia* L. have demonstrated activity against tuberculosis and the stomach ulcer-causing bacteria *Helicobacter pylon*. The bitter gourd leaves' juice also helps in the treatment of early stages of cholera and diarrhea (Ganesan et al. 2008).
6. ***Anticancerous and antitumorous compounds:*** A novel phytochemical in bitter gourd has clinically demonstrated the ability to inhibit an enzyme named guanylate cyclase. This enzyme is thought to be linked to the pathogenesis and replication of not only psoriasis, but leukemia and cancer as well. Bitter gourd extract inhibits cancer cell growth (Salehi et al. 2018) and liver cancer and leukemia in humans (Grover and Yadav 2004; Fang et al. 2012a). The chemical compound DMC (3β,7β-dihydroxy-25-methoxycucurbita-5,23-diene-19-al) derived from wild bitter gourd possesses hypoglycemic and antitumor activities (Weng et al. 2013; Bai et al. 2016; Pehlivan 2021). It is also reported that the Thai bitter gourd contains anticarcinogens and chemopreventive compounds (Yasui et al. 2005; Gayathry and John 2022). MAP30 protein of bitter gourd protects against liver cancer (Fang et al. 2012a). RNase MC2 present in bitter gourd seeds protects against breast cancer and has anticarcinogenic effects towards liver cancer cells in humans (Fang et al. 2012b). Studies have reported that bitter gourd possesses anticarcinogenic properties and thus can be used as a cytotoxic agent against several types of cancers (Fig. 8.2) (Haque et al. 2011: Bortolotti et al. 2019; Altaf and Khan 2021). The bitter gourd extracts modulate signal transduction pathways for inhibition of breast cancer cell growth (Ray et al. 2010; Bortolotti et al. 2019).

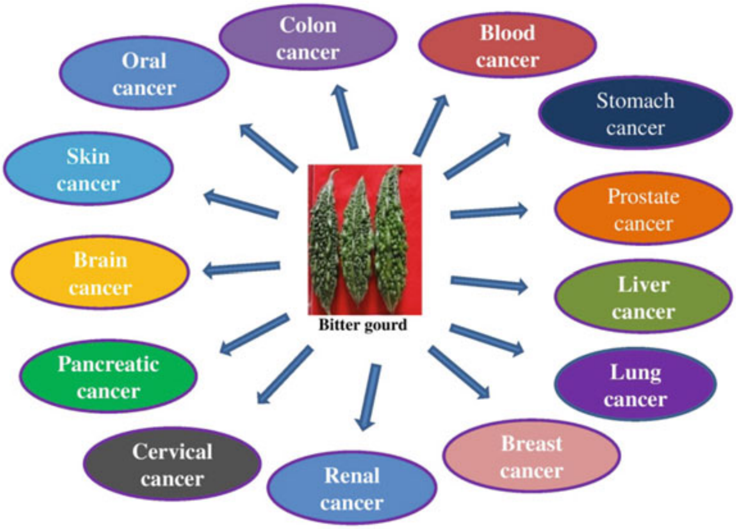

Fig. 8.2 Bitter gourd for different types of cancer prevention

7. ***Respiratory/asthma problems:*** The paste of the leaves of the bitter melon is mixed with equal amounts of the paste of *tulsi* leaves. This is taken with honey each morning as a treatment and prevention for respiratory problems such as asthma, bronchitis, common colds, and pharyngitis.
8. ***Skin and other diseases:*** In the case of scabies, ringworm, psoriasis, etc., one cup of bitter melon juice must be taken each morning on an empty stomach. This juice can be made more potent by adding a teaspoonful quantity of lime juice in it. It is also used in the prevention of leprosy in vulnerable regions of the world. The bitter gourd powder consumption can help in body weight gain and reduction in blood glucose level; an increase in the level of energy metabolism and glucose metabolism-associated pathways could also be affected in high-fat diet-fed mice (Bian et al. 2016). The seeds are also useful for leukemia therapy (Soundararajan et al. 2012). The leaf paste of bitter gourd plant in hot water could be helpful in the control of several diseases like treatment of leprosy, jaundice, ringworm, piles, bowel movement, cough, chest pain, and congestion (Kandangath et al. 2015; Gayathry and John 2022). Bitter gourd leaves extracted through BACTEC 460 can inhibit *Mycobacterium tuberculosis* (Frame et al. 1998). Bitter gourd extract possesses therapeutic properties for regeneration of tissues and wound healing properties and stimulates the proliferation of dermal fibroblasts in humans (Tan et al. 2016). Fruits have been used as a folk remedy for asthma, tumor, skin infections, and hypertension (Shubha et al. 2018). Bitter gourd has emetic, purgative, anthelmintic, and anti-lipolytic properties. The non-nitrogenous neutral principle known as charantin, on hydrolysis, gives glucose and sterol (Zaini et al. 2018). Regular use of bitter gourd juice prevents chronic fatigue and boosts body stamina (Shubha et al. 2018). It also prevents

jaundice by strengthening liver function and helps in the treatment of hangover by detoxifying and nourishing liver. Three teaspoonful of juice with a glassful of buttermilk is advised to take in the morning in empty stomach for a month to help in piles treatment (Shubha et al. 2018). Bitter gourd fruit juice also has anti-dementia (Joshi et al. 2017), antibacterial, and antifungal properties (Mahmood et al. 2019).

9. ***Blood impurities and diabetes:*** Bitter gourd is used as a blood purifier due to its bitter tonic properties. It can heal boils and other blood-related problems that show up on the skin. For treatment, a cupful of juice of the bitter melon must be taken each day in the morning, with a teaspoon of citrus lemon juice in it. It also enhances the GLP-1 secretion, thereby controlling glucose homeostasis through an insulin effect (Huang et al. 2013). *Diabetes mellitus* has become the third most lethal disease of humans and is increasing rapidly (Ogbonnia et al. 2008; Perera et al. 2021), which is alone responsible for five leading causes of death across the world (Joseph and Jini 2011; Shivanagoudra et al. 2019). Up to 30% of patients use complementary and alternative medicine for diabetes (Raman et al. 2012). Recently, preclinical studies have proved that bitter gourd has potential efficacy to alter type 2 diabetes (Shivanagoudra et al. 2019; Bortolotti et al. 2019; Venugopal and Dhanasekaran 2020; Gayathry and John 2022). The use of fried karela on a daily basis maintained the level of glucose in a diabetic patient and subsequently serum insulin level also did not increase (Leatherdale et al. 1981). Significant results were obtained in reduction of blood glucose, i.e., 21.5%, 49.2%, and 28% at 30 min, 4 h, and 12 h, respectively, after consumption of bitter gourd fruits (Baldwa et al. 1977). Consumption of its fruits enhances beta cells (Ahmed et al. 1998), which act as vegetable insulin (Leung et al. 2009). Several biochemical and animal model experiments have generated abundant data for the antidiabetic effects of bitter gourd due to the presence of several bioactive health compounds, primarily charantin (Shivanagoudra et al. 2019; Perera et al. 2021; Gayathry and John 2022). Charantin, isolated from fruits of bitter gourd, possesses hypoglycemic activities which lower blood glucose (Zaini et al. 2018). Charantin was found to be more potent than tolbutamide. The isolated compounds from bitter gourd fruits like 3β,7β,25-trihydroxycucurbita-5,23(E)-dien-19-al, charantal, charantoside XI, and 25-£-isopropenylchole-5,6-ene-3-*O*-D-glucopyranoside were found to be potential antidiabetic compounds (Shivanagoudra et al. 2019).
10. ***Anti-HIV activities:*** The α- and β-momorcharin proteins in different parts of bitter gourd plant like seeds, leaves, and fruits have anti-HIV properties in vitro, which can suppress HIV-1 integrase (Au et al. 2000), whereas presence of MRK29 has the ability of inhibition of viral reverse transcriptase (Wang and Ng 2001). The seeds have been used as a potential contraceptive in China (Shubha et al. 2018).
11. ***Regulate and decrease cholesterol level:*** High level of cholesterol can cause a risk of heart disease. Various studies in animals reported that eating bitter melon may decrease cholesterol level and support heart health. Bitter melon extracts led to a significant decrease in total cholesterol level, bad LDL cholesterol, and

triglycerides (Naz et al. 2016). Low-density lipoprotein (LDL) or bad cholesterol in layman forms plaque in arteries, which promotes atherosclerosis, heart attack, and several other coronary heart problems. Bitter gourd juice has anti-inflammatory properties (Chao et al. 2014; Dandawate et al. 2016; Shivanagoudra et al. 2019; Bortolotti et al. 2019; Perez et al. 2021; Perera et al. 2021; Gayathry and John 2022) and helps in lowering the levels of LDL. It is also a rich source of Fe, which helps in boosting immunity and protects heart disease in humans. Saeed et al. (2018) observed that higher doses of bitter melon showed more decrease in cholesterol level.

12. ***Promote gut health:*** The regular use of bitter gourd has a positive impact on gut health. It helps in the treatment of intestinal disorders like constipation, stomachache, and irritable bowel syndrome (IBS) and also helps in killing parasites that enter into the digestive system. Due to its high fiber content and natural laxative properties, it is recommended by doctors for better digestive system and hemorrhoid relief.
13. ***Immunity boosting:*** Bitter gourd is a rich source of vitamin C, which possesses plenty of antioxidant properties. These antioxidants are helpful in the multiplication of immune cells (WBCs). This helps in strengthening the immune system and preventing allergies. Bitter gourd can fulfil the recommended dietary intake (RDI) of vitamin C (98.5 mg).
14. ***Controls obesity:*** Bitter gourd is well known for its fat-burning activities. Regular use of bitter gourd juice in an empty stomach can help in faster fat metabolism in humans. Due to several bioactive compounds, it helps in the secretion of bile acids. Bitter gourd is very low in calories, which makes it excellent for people looking for weight loss.
15. ***Reduce hangovers:*** The juice of bitter melon is emetic, which can induce nausea and clean the system within. Any person who is suffering from a hangover due to too much alcohol can sip the juice in an empty stomach, which helps flush out the alcohol and maintain a healthy liver. The presence of antioxidants in juice strengthens the liver, thus preventing its failure and avoiding intoxication, which is due to too much alcohol.

The extensive studies on antidiabetic and anticancer effects of bitter gourd fruits in animals and humans with results obtained have been summarized in Tables 8.5 and 8.6.

Several varieties of bitter gourd have been developed in India for higher yield (Singh et al. 2022), nutrition, health, and value addition (Table 8.7). These varieties are rich in antioxidants, FRAP, SOSA, total polyphenols, potential source of antidiabetic properties (saponin and charantin), vitamin C, vitamin B7, vitamin D, vitamin K, and minerals (calcium, manganese, zinc, and iron) (Tomar et al. 2018; Behera et al. 2022).

Table 8.5 Antidiabetic properties of bitter gourd studied in vitro and in vivo (Gayathry and John 2022)

S. no.	Studies conducted	Treatments	Results	References
1.	Randomized placebo-controlled single-blinded clinical trial with 52 individuals with prediabetics	Daily consumption of bitter gourd powder for 8 weeks: Crossover design, 8 weeks for each study period and 4 weeks' washout	↓ Fasting plasma glucose	Krawinkel et al. (2018)
2.	In vivo study in high-sucrose diet-induced diabetic rats	Bitter gourd powder @ 150 and 300 mg/kg body weight for 56 days	↓ Blood glucose level ↑ Serum insulin level	Mahwish et al. (2018)
3.	In vivo study on diabetic-induced mice by streptozotocin	Extract of bitter gourd (aqueous and ethanol) @ 200 mg/kg weight of mice for 3 weeks	↓ Blood glucose level	Yousaf et al. (2016)
4.	In vivo assay in streptozotocin-induced diabetic rats	Protein extract form bitter gourd fruits @ 10 mg/kg body weight was fed to rats. After 10, 30, 60, and 120 m of oral administration, blood samples were drawn	↓ Peak blood glucose	Poovitha and Parani (2016)
5.	In vitro α-amylase and α-glucosidase activities	Spectrophotometric assay of protein extracts from bitter gourd	↓ α-Amylase and α-glucosidase activity on par with acarbose	Poovitha and Parani (2016)
6.	Preliminary clinical trials on non-insulin-dependent diabetes mellitus patients	Tablets made from bitter gourd powder having 20 mg polypeptide @ 4–6 tablets/day half an hour before meals, t.d.s. for 8 weeks	Effective oral adjunct hypoglycemic effect without any side effects	Salam et al. (2015)
7.	In vivo rat model with induced diabetes with streptozotocin	Fruit extracts @ 1.5 g/kg of rats for 28 days after diabetes induction	↑ Vascular compilation by decreasing blood pressure, serum total cholesterol, triglyceride levels, aortic tissue MDA level ↑ Aortic nitrous oxide level	Abas et al. (2015)
8.	Randomized clinical trials on diabetic patients	Fermented bitter gourd beverage @	↓ Diabetic symptoms, fasting,	Devaki and Premavalli (2014)

(continued)

Table 8.5 (continued)

S. no.	Studies conducted	Treatments	Results	References
		45 mL during morning	and postprandial blood sugar	
9.	Multicenter randomized, double-blind, active control trial in newly diagnosed type 2 diabetes patients	Powdered bitter gourd capsules @ 500 mg containing 0.04–0.05 (w/w) of charantin @ 500/1000/2000 mg bitter gourd per day and 1000 mg metformin per day for 4 weeks	Hypoglycemic effect ↓ Fructosamine levels from baseline in 2000 mg treated patients. But less effect than metformin 100 mg per day	Fuangchana et al. (2011)
10.	In vivo study in insulin-resistant db/db mice	Whole-fruit powder, a lipid fraction, a saponin fraction, or hydrophilic residue of bitter gourd daily @ 150 mg/kg body weight for 5 weeks	↓ Glycated Hb level in all treatment groups ↓ Lipid peroxidation in adipose tissue ↓ Protein tyrosine phosphate 1B activity in skeletal muscles	Klomann et al. (2010)
11.	In vitro trial in streptozotocin-induced diabetic rats	Bitter gourd powder incorporated at 10% level at the expense of equivalent amount of corn starch in AIN 76 basal diet for 45 days	Improved diabetic status by significant reduction in glomerular filtration rate	Shetty et al. (2005)

8.2.5 Mode of Action of Bitter Gourd and Its Extract Against Diabetes, Inflammation, and Cancer

The various extracts and components of bitter gourd are believed to exert their hypoglycemic effects in different physiological, biochemical, and pharmacological modes (Garau et al. 2003; Bhushan et al. 2010). There are different modes of action of bitter gourd, and its extracts have been reported as stimulation of peripheral and skeletal muscle glucose utilization (Akhtar et al. 2011), inhibition in the uptake of intestinal glucose (Abdollah et al. 2010), inhibition of adipocyte differentiation (Nerurkar et al. 2010), suppression of key gluconeogenic enzymes(Shibib et al. 1993; Singh et al. 2011), stimulation of key enzyme of HMP pathway (Shibib et al. 1993), and preservation of islet β-cells and their functions (Gadang et al. 2011). Bitter gourd extract was also reported to suppress the activation of mitogen-activated protein kinase (MAPKs) and stress-activated protein kinase (Kim and Kim 2011). The result of the findings suggests that bitter gourd protects pancreatic β-cells through downregulation of MAPKs and NF-KB in MIN6N8 cells. The extract of bitter gourd fruits improves the serum and liver lipid profiles and

Table 8.6 Anticancer properties of bitter gourd studied in vitro and in vivo (Gayathry and John 2022, with modification)

S. no.	Type of study	Assay conducted	Chemical ingredients	Plant part	Results	References
1	In vitro assay in lung cancer (A 549), breast cancer (MCF 7), chronic myeloid leukemia (K 562), and T-cell leukemia (Jurkat cells)	MTT	Ethanol and acetone extract	Fruit and seed	Antitumor activity of 90, 92, 85, and 87% against K562, MCF7, and Jurkat cell lines, respectively, by ethanolic extract	Gunes et al. (2019)
2	Colon, pancreatic, prostate cancer, and glioma cells		Fruit extract MAP30	Fruits	Inhibited cancer stem cell and stem cell markers SOX2, OCT4, NANOG, and CD44, suppressed Wnt/β-catenin signaling	Jiang et al. (2018); Dhar et al. (2018)
3	In vivo and in vitro model of head and neck cancer (modulation in immune system)		Kuguacin J	Crude extract	Inhibit immune checkpoint gene PD1, cytokines s100a9, IL23a, IL1β, induced natural killer cell-mediated cytotoxicity. Inhibit Treg cell and Th17 cell population	Bhattacharya et al. (2017); Sur et al. (2018)
4	In vitro assay in human colon cancer cell lines	Flow cytometry apoptosis	Novel protein BG 4	Seeds	Cytotoxicity towards HCT-116 and HT-29 cell lines with ED50 values of 134.4 and 217 μg/mL, respectively	Dia and Krishnan (2016)
5	In vitro assay on breast cancer cell lines	MTT	3β,7β,25-trihydroxycucurbita-5,23 (E)-dien-19-al (TCD)	Whole plant	Suppression in proliferation of MCF-7 and MDA-MB-231 cell lines with IC50 values of 19 and 23 μM, respectively, at 72 h	Bai et al. (2016)
6	In vitro assay on cervical and breast cancer cell lines	Sulforhodamine B	Ethanolic extract	Fruit	Effective cytotoxicity towards HeLa and MCF7 cell lines	Shobha et al. (2015)
7		Flow cytometry assay in Hep G2 cells	MAP protein	Seeds	Inhibition in cell viability with an IC_{50} value of 28.6 μM for	Fang et al. (2012b)

(continued)

Table 8.6 (continued)

S. no.	Type of study	Assay conducted	Chemical ingredients	Plant part	Results	References
	In vitro study in liver cancer cell lines In vivo studies in nude mice	and Hep G2-bearing mice			24 h and 7.8 μM for 48 h in Hep G2 cells and effective antitumor potential in Hep G2-bearing mice	
8	In vitro assay in human nasopharyngeal carcinoma cells In vivo assay in athymic nude mice	Flow cytometry apoptosis TUNEL staining assay	Lectin	Seeds	Potent cytotoxicity towards cell lines CNE 1 and CNE 2 at IC50, 6.9 and 7.4, respectively	Fang et al. (2012b)

Table 8.7 Bitter gourd varieties developed at ICAR-Indian Agricultural Research Institute, New Delhi, for higher yield, nutrition, health, and value addition

Name of variety	Special features
Pusa Aushadhi 	Fruits are light green; average fruit length is 16.5 cm and weight is 85 g. First fruit picking starts at 48–52 days after sowing. The average fruit yield is 150–190 q/ha. Higher female:male flower ratio (3:1). Rich in total carotenoids (957.16 μg), lutein (85.42 μg), lycopene (122.64 μg), β-carotene (27.96 μg), antioxidants, FRAP (5728), SOSA (3056), and total polyphenols (6.51). A potential source of antidiabetic properties (saponin 7.1 mg/100 g, charantin 3.91 mg/100 g).
Pusa Rasdar 	Suitable for protected cultivation using manual pollination or honeybees as a source of pollination. Fruits are juicy, smooth, and non-prickled with tender skin. The average fruit weight is 110 g and yield is 4.54 q/100 m^2 insect-proof net house. Total carotenoids (973.39 μg/100 g), lutein (104.76 μg/100 g), lycopene (63.87 μg/100 g), β-carotene (30.88 μg/100 g), antioxidant, FRAP (4920), SOSA (2500), and total polyphenols (4.30). Source of vitamin C (54.26 mg/100 g) and vitamin B7 (17.89 μg/100 g). Suitable for juice extraction
Pusa Purvi 	Small, fruited variety for making stuffed cuisines. Fruits are dark green and small (4–5 cm long and 3–4 cm diameter) and have crispy flesh. High dry matter content with average fruit yield is 87.8 q/ha. Good source of minerals (calcium, manganese, zinc, and iron) and antioxidants, vitamin D (7.31 μg/100 g), vitamin K (251.15 μg/100 g), vitamin B7 (29.66 μg), and vitamin C (76.16 mg)
Pusa Hybrid-2 	Fruits are dark green, medium long, and thick. Fruit length is 12.5 cm and diameter is 4.5 cm with irregular and smooth ridges. The average fruit weight is 85–90 g with an average yield of 182 q/ha. It contains minerals, viz. iron (155 ppm), calcium (0.35%), and antioxidants
Pusa Hybrid-4 	First predominantly gynoecious hybrid. The average yield is 222 q/ha. Fruits are dark green, medium long, and thick (average fruit length 16 cm and diameter 5.5–6.5 cm) with 5–6 discontinuous narrow ridges with an average fruit weight of 60 g and marketable maturity at 45–50 days. Source of iron (18.20 mg/100 g), calcium (1.97 mg/100 g), zinc (3.27 mg/100 g), Mn (2.1 mg), and potassium (26.92 mg)
Pusa Hybrid-5 	Fruits are attractive green, average fruit length is 15.5 cm, diameter 6.0–6.5 cm with 5–6 discontinuous narrow ridges. First fruit harvesting in 44–48 days after sowing with an average fruit weight of 70 g. Average fruit yield is 24.5 t/h. Rich in total carotenoids (945.16 μg), lutein (88.42 μg), lycopene (123.64 μg), β-carotene (31.96 μg), antioxidants, FRAP (5766), and total polyphenols (6.51). The potential source of antidiabetic properties (saponin 7.54 mg/100 g, charantin 3.51 mg/100 g)
	Higher female-to-male flower ratio (2:1). Fruits are attractive green, average fruit length 16.4 cm and diameter 5.0–5.5 cm with 5–6

(continued)

Table 8.7 (continued)

Name of variety	Special features
Pusa Hybrid-6 	continuous narrow ridges. First fruit harvesting in 42–46 days after sowing with an average fruit weight of 65–70 g. The average fruit yield is 35.04 t/h in zone I (Himachal Pradesh, Uttarakhand, and Jammu and Kashmir). Seeds of female parent and hybrid are black and dark brown in male parent. Good source of minerals (calcium, manganese, zinc, and iron) and antioxidants like carotenoids (939.16 μg), lutein (83.42 μg), lycopene (136.64 μg), β-carotene (25.96 μg)

serum glucose levels by modulating PPAR-γ gene expression (Gadang et al. 2011). Protein tyrosine phosphatase 1B (PTP1B), a negative regulator of insulin signaling, has been used as a possible drug for the treatment of type 2 diabetes (Hoang et al. 2010). Bitter gourd has direct effect on the reduction of blood glucose level (Taylor 2002), and insulin plays an important biochemical role in stimulating the uptake of glucose for energy production (Sattiel and Khan 2001; Kumar and Clark 2005). Studies have confirmed that the alcoholic extracts of bitter gourd fruit can inhibit the activities of fructose 1,6-diphosphatase and glucose 6-phosphatase and at the same time also stimulate the action of glucose-6-phosphatase dehydrogenase (Shetty et al. 2005). Bitter gourd extracts also stimulate peripheral cell glucose uptake (Cummings et al. 2004; Akhtar et al. 2011). Bitter gourd and its extract can directly regulate blood glucose; it can either regulate how much glucose is absorbed by the gut into the blood following a meal or stimulate glucose uptake into skeletal muscle cells just like insulin (Hanhineva et al. 2010). It has been widely demonstrated that bitter gourd extract lowers glycemia in patients affected by type 2 diabetes (Bortolotti et al. 2019; Shivanagoudra et al. 2019).

Several bitter gourd extracts have been found in regulating inflammation, particularly through NF-$_{\kappa}$B signaling pathway inhibition: in RAW 264.7 cells, bitter gourd reduced TNF-α production, induced by LPS, thereby decreasing the expression of LPS-induced inflammatory genes, including those for IL-1α, IL-1β, and TNF-α (Kobori et al. 2008; Perez et al. 2021). Acetone and methanol extracts decreased LPS-induced expression of genes related to the development of inflammasome complex (Shivanagoudra et al. 2019; Perez et al. 2021). The purified triterpenoids in the study had differential anti-inflammatory effects on the expression of the genes *IL-1β, NF-Kb, NLRP3, Pycard, Casp1, HMGB1,* and *HMOX-1* (Perez et al. 2021). The bitter gourd extracts were reported to be decreasing the expression of inducible NO synthase and cyclooxygenase-2 and suppressing NF-κB and activator protein-1 (AP-1) activity via downregulation of ERKs and Akt (Hsu et al. 2012). Use of bitter gourd powder as diet supplement in a high-fat diet obese mice lowered systemic inflammation by reducing TNF-α and IL-6 serum levels and remodeled key functions of the colon by affecting the expression of genes involved in the regulation of inflammation (Bai et al. 2016, 2018). The fruit extract showed anti-inflammatory activities in human lung epithelial cells by upregulating microRNAs miR-221 and miR-222 (Sung et al. 2018), which indicated that gene regulation might be due to

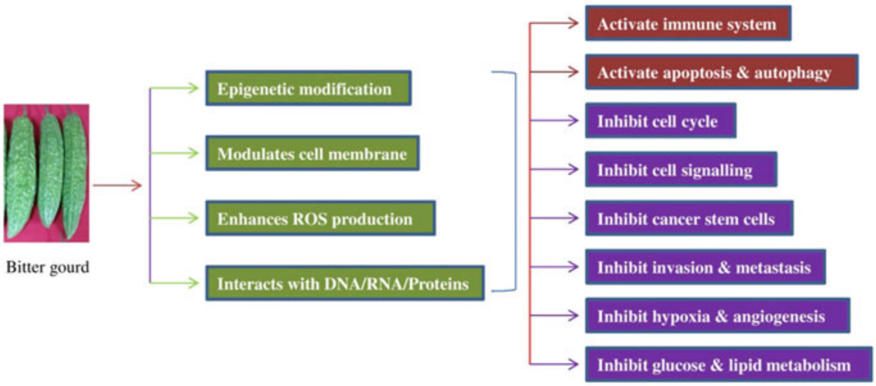

Fig. 8.3 Molecular mechanisms of cancer prevention and therapy using bitter gourd

epigenetic modification activity. The isolated compounds from bitter gourd like 3β,7β,25-trihydroxycucurbita-5,23(E)-dien-19-al, charantal, charantoside XI, and 25-£-isopropenylchole-5,6-ene-3-*O*-D-glucopyranoside were found to be potential anti-inflammatory compounds (Shivanagoudra et al. 2019).

The potential antioxidant activities of bitter gourd extracts have been demonstrated in various in vitro studies. Pretreatments of neuroblastoma cells with bitter gourd extracts were found to attenuate cytotoxic oxidative stress induced by H_2O_2 by increasing intracellular scavenger activity and reducing H_2O_2-induced activation of the JNKs, p38, and ERK1/2 MAPK signaling pathways (Kim et al. 2018). Bitter gourd extract reduces neuro-inflammation, ameliorating neurodegenerative diseases (Nerurkar et al. 2011; Shivanagoudra et al. 2019; Perez et al. 2021). The key enzyme xanthine oxidase induces hyperuricemia and gout, which is involved in many inflammation-related diseases (Battelli et al. 2016, 2018; Shivanagoudra et al. 2019; Perez et al. 2021; Perera et al. 2021). Cucurbitane-type triterpene glycosides isolated from bitter gourd stems and fruits inhibit xanthine oxidase activity (Lin et al. 2012). Cucurbitane triterpenoids extracted from bitter gourd leaves strongly suppress *Porphyromonas gingivalis*-induced IL-8, IL-6, and IL-1β levels (Tsai et al. 2016).

It is thought that bitter gourd extracts possess anticancer properties, which could rely on the ability to modulate several deregulated signaling pathways in different types of cancer (Bortolotti et al. 2019) (Fig. 8.3). The recently identified bitter gourd cucurbitane-type triterpene glycosides showed significant antitumor activity in hepatic carcinoma-derived cell lines (Yue et al. 2019). The bitter gourd extract and its compound suppress the function of oncogenes and induce the expression of tumor suppressive genes at a time to exhibit anticancer effect (Sur and Ray 2021). The results of the RNA sequence analysis showed that 4482 genes were differentially regulated in the prevention of mouse tongue cancer by use of bitter gourd extract (Sur et al. 2018). These genes significantly regulate various biological processes including signal transduction, apoptosis process, metabolic process, cell adhesion,

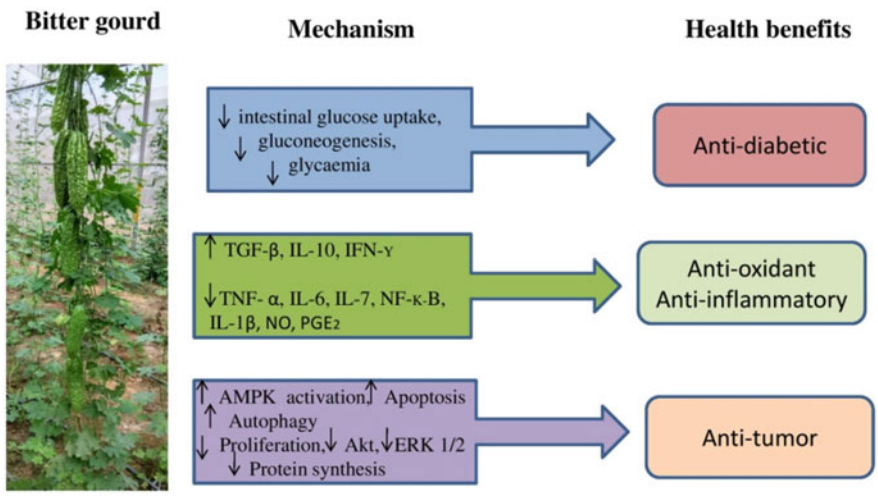

Fig. 8.4 Mechanism of bitter gourd for pharmacological effects

lipid metabolism, immune system process, angiogenesis, ossification, and G1/S transition of mitotic cell cycle (Sur and Ray 2021).

Bitter gourd extract inhibits the activity of calcium-independent phospholipase A2 (iPLA2) in head and neck cancer cells (Sur et al. 2019). iPLA2 is expressed in mammalian cells and involved in several biological processes including lipid metabolism, phospholipid remodeling, cell differentiation, maintenance of mitochondrial integrity, cell proliferation, signal transduction, and cell death (Sur and Ray 2021) (Fig. 8.4). Most of the anticancer activities have been only observed in xenografted mice; therefore, there is a need to study the possible use of bitter gourd extract as nutraceuticals in the treatment of cancer in humans.

8.2.6 Value-Added Products from Bitter Gourd

Nearly 25% of postharvest losses have been reported in bitter gourd. The major reason for this is mechanical damage during transportation due to warty nature of the fruit and continuous fruit ripening after harvest. If fruits are packed in gunny bags and carefully transported, these postharvest losses can be minimized to a great extent. If harvested at immature stage, bitter gourd fruits can be stored at 13 °C temperature for 5–6 days. Generally, bitter gourd is preferred as fresh or in different recipes like soups, salads, boiled, deep-fried, steamed, juice, pickled, snacks, and bakery products (Singh and Sagar 2013). Several processing technologies have been investigated for value addition of bitter gourd to produce widely accepted products with extended shelf life and round-the-year availability. Bitter gourd can also be incorporated in commonly consumed foods/vegetables to reduce the bitter taste of bitter gourd (Snee et al. 2011). Among value-added products, juice, beverages,

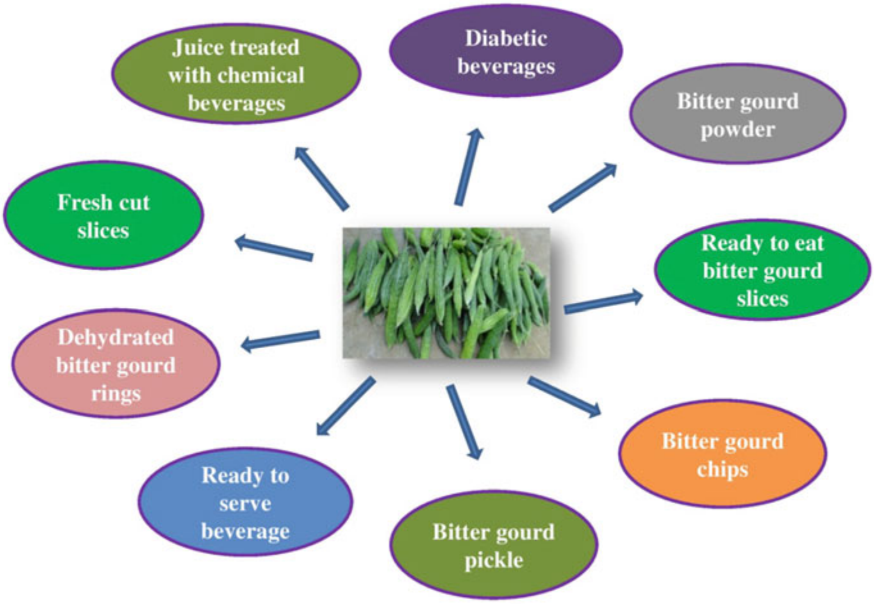

Fig. 8.5 Value-added products from bitter gourd fruits

chips, slices, pickles, and dried powder are commonly used products from bitter gourd fruits (Fig. 8.5).

Juice and beverages Usually, bitter gourd fruit juices alone are not preferred due to their high bitter taste. Therefore, bitter gourd fortified juice using suitable formulation, processing, and storage is needed to make it palatable and acceptable to consumers. The juices of lemon, amla, pomegranate, and sweet orange are recommended to add along with bitter gourd juice to enhance its nutritional value and palatability to consumers. Due to the presence of several bioactive compounds, its juice is recognized as a natural source of nutraceuticals. Bitter gourd juice treated with potassium metabisulfite (KMS) had higher nutrient stability than Na-benzoate (Kaur and Aggarwal 2014). Bitter gourd extract using artificial sweetener was employed to develop functional and dietetic beverage and preserved at refrigerated temperature for a long duration with good flavor, palatability, and all nutritional properties (Din et al. 2011). Different concentrations of bitter gourd juice, sugar, and citric acid were used to prepare ready-to-serve bitter gourd beverages (Satkar et al. 2013). These researchers reported that ready-to-serve bitter gourd beverage could be made using the levels of juice 12.5% sugar −15 g, citric acid 0.29 g, and water 76 mL for 100 mL of beverage and kept refrigerated at (5 ± 1 °C) temperature for up to 3 months without changing the chemical and sensory qualities. The fermented bitter gourd-grape beverage had the highest antidiabetic potential compared to bitter gourd and grape juice alone (Maselesele et al. 2022).

Chips Osmo-air-drying of bitter gourd chips is done by soaking with 0.2% KMS for 10 min followed by 2%, 6%, and 10% of NaCl and 1%, 3%, and 5% of acetic acid for 90 min, blotting and dried at 60 °C for 8 h (Kumar et al. 2016). Bitter gourd chips prepared with 10% NaCl had better color and provided large-scale acceptability; they might be kept at ambient conditions for 3 months without loss of organoleptic quality and are microbiologically safe. Bitter gourd chips should be packed into LDPE bags and stored in cool and dry place for longer storage.

Dried powder Drying of bitter gourd retains all bioactive compounds such as ascorbic acid, total carotenoids, β-carotene, and total chlorophyll content (Singh and Sagar 2013; Patel et al. 2019). The lyophilized superfine powder had higher antidiabetic activity than hot-air-dried powder because reduced fasting blood glucose level was higher in lyophilized powder as compared to hot-air-dried powder (Zhu et al. 2012). Therefore, bitter gourd powder could be used as a suitable functional food ingredient. Bitter gourd extract might be applied as a natural antioxidant instead of a synthetic antioxidant in the food sector for extending the shelf life of food commodities owing to higher natural plant phenolics and antiradical power (Horax et al. 2005, 2010; Akyuz et al. 2020).

Slices Fresh-cut bitter gourd slices (1 cm thick) might be kept in modified atmosphere packaging with low-density polyethylene bag for 15 days at 8 °C without deterioration of nutritional quality (Preetha et al. 2015). Fermented bitter gourd slices treated with 3% dry salt were in highly acceptable levels as fermented ready-to-eat vegetables, and maximum overall acceptability was also found during storage period (Silva et al. 2016). The dried slices can be used for preparation of bitter gourd tea which is known as herbal tea (Gayathry and John 2022).

Pickle Bitter gourd pickle is prepared by cutting bitter gourd fruits into small pieces. To enhance the shelf life of pickle, keep it in mustard oil enough to submerge the pickle completely and also add powdered spices and condiments for long-term storage. The procedure for bitter gourd pickle preparation is given in Fig. 8.6.

8.3 Conclusion

As discussed in this chapter, bitter gourd is an important vegetable that not only provides nutrition but also possesses several compounds which are medicinally important and help in the treatment of several diseases and sources of important health-promoting substances. Various chemical compounds have been used for treating important diseases like diabetes, stomach disorders, pain, and viral and several bacterial infections as well as deadly diseases like cancer and HIV. Since bitter gourd possesses over 225 different medicinal constituents, it is known as a versatile plant worthy of treating almost any disease inflicted in humans. These medicinal constituents seem to exert their beneficial effect *via* different mechanisms to control and treat *diabetes mellitus*. Therefore, bitter gourd may be a better option

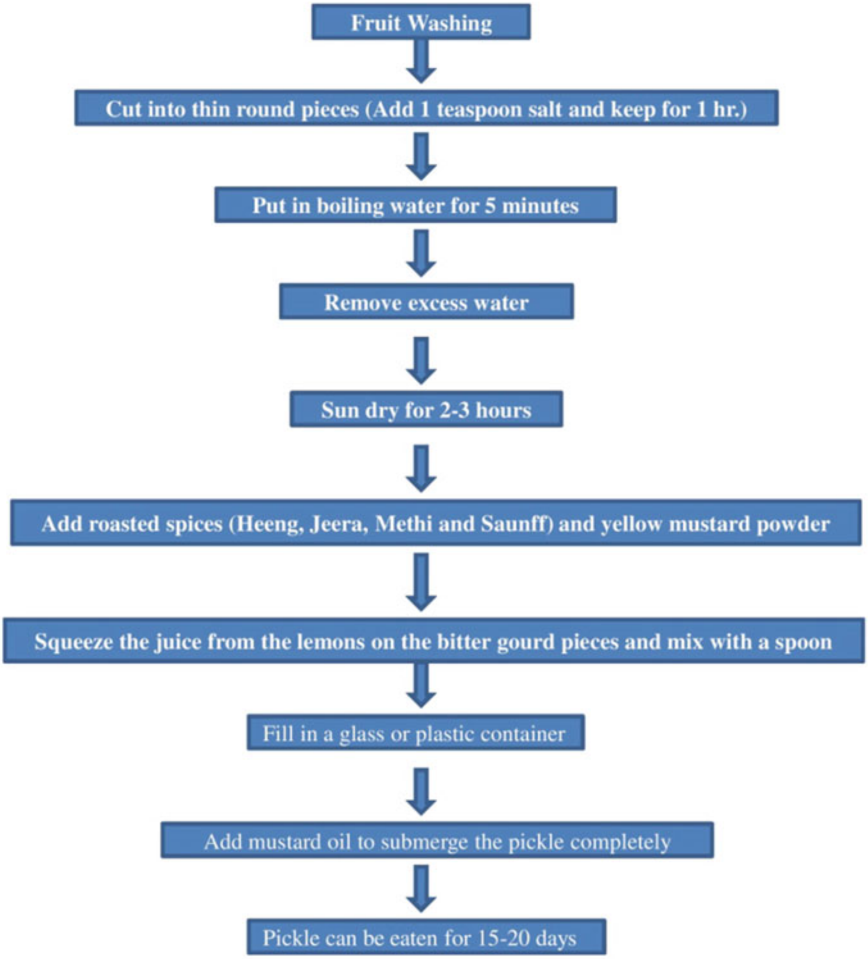

Fig. 8.6 Pickle preparations from bitter gourd fruit

for ethnic minorities who have a high prevalence of diabetes but believe in natural treatments. These attributes make bitter gourd an economically important crop species for genetic improvement.

8.4 Future Directions

Up to now, research on varietal development and bioactivities of bitter gourd has developed rapidly, but efforts are also required for the development of high nutrient- and nutraceutical-rich genotypes with consumer-specific preferences. The future research focus should be interdisciplinary work involving nutritionists, and physicians to elucidate mechanism of action and long term medical studies to standardized optimum dosage, access efficacy and safety in a clinical setting as well as involvement of vegetable breeders for improving nutritional quality by selecting diverse genotypes, and food technologists for different value-added products, need to be initiated to ensure consumer acceptance at the broad level. There is also lack of information about metabolism and bioavailability of discovered compounds in bitter gourd and possible side effect on humans, especially with regard to long-term consumption. Last but not least, the majority of studies on bioactive compounds have been performed on animals and cell level; hence, their impact on humans needs to be demonstrated.

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Nutrition in Potato and Its Food Products 9

Brajesh Singh, Pinky Raigond, Som Dutt, Milan K. Lal, Arvind Jaiswal, Sushil S. Changan, and Bandana Koundal

Abstract

Potatoes have been consumed since ages; however, efforts to popularize its nutritional significance have increased its importance as an alternative for food and nutritional security. Accelerated growth of potato in the developing world including Asia and Africa can help to substantiate the food and nutritional requirements of the undernourished in these regions. This chapter focuses on the nutritional importance of potato in terms of energy and carbohydrates, proteins and amino acids, vitamins, minerals, antioxidants, novel health-promoting compounds, and also antinutrients present in potato. This chapter also includes the nutritional significance of popular potato products. This chapter helps to popularize potato as a healthy food and enhances its acceptance as a staple healthy food. It also helps to remove misconceptions associated with potato consumption.

Keywords

Potato · Potato products · Energy · Carbohydrates · Proteins · Amino acids · Vitamins · Minerals · Antioxidants · Novel health-promoting compounds

B. Singh (✉) · P. Raigond · S. Dutt · M. K. Lal · S. S. Changan
ICAR-Central Potato Research Institute, Shimla, Himachal Pradesh, India

A. Jaiswal
ICAR-Central Potato Research Institute Regional Station, Jalandhar, Punjab, India

B. Koundal
ICAR-Central Potato Research Institute Regional Station, Meerut, Uttar Pradesh, India

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9.1 Introduction

Food security is assumed ensured when all people at all the times have access to sufficient, safe, nutritious food to maintain a healthy and active life. Food security depends on the availability of food, affordability, and proper utilization of food. Generally, surplus food grains are considered to be important for nutritional security, but it is not always true to all the population, as affordability is another major issue. Few indicators of food and nutritional security are proportion of undernourished population, <5-year-old underweight children, and mortality of <5-year-old children (Singh and Rana 2013). Undernourished population and <5-year-old underweight children are high in Bangladesh and Indian subcontinent, with the status remaining alarming over the years (Figs. 9.1 and 9.2). Globally, India stood second in child malnutrition after Bangladesh. Still, more than 40% children are underweight in India, which is a great concern. Though the rate of mortality of <5-year-olds has decreased over the period, it is still up to 6.3% in India (Fig. 9.3). This needs to be addressed further through nutritious and sufficient food access to pregnant women and children. To overcome this situation, those fruits and vegetables should be popularized which are available throughout the country in all the seasons and are in reach of all income groups, especially poor (Singh et al. 2015).

Potatoes' mild flavor and its utilization in combination with other foods have made it a widely accepted food worldwide. Potatoes have been popular since long due to their nutritional value, especially high content of ascorbic acid that helps to prevent scurvy. The Food and Agriculture Organization (FAO 2008) has emphatically recommended potato as a potential crop for the poorest of the poor, to ensure global food, nutritional, and income security in future. Potato production and productivity have remained higher in comparison to maize, rice, and wheat. As serious food security problem will occur in future due to various reasons such as stagnation of crop yields, exhausting soils, and increasing population in the country,

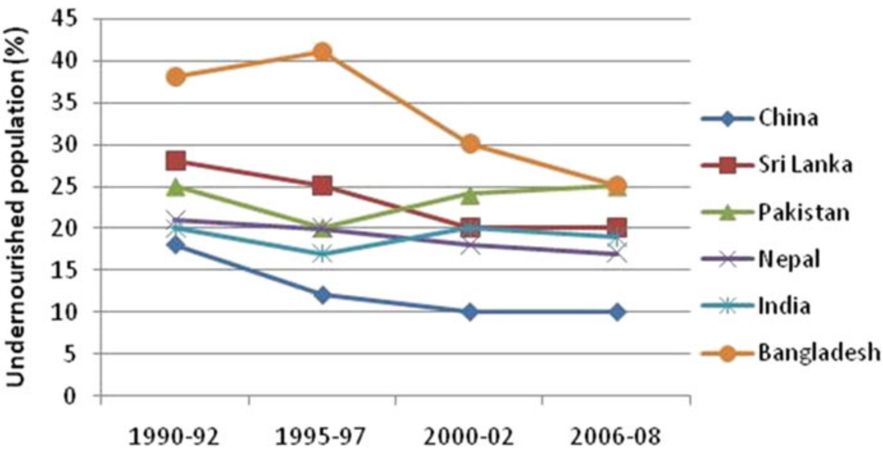


Fig. 9.1 Undernourished population in different countries

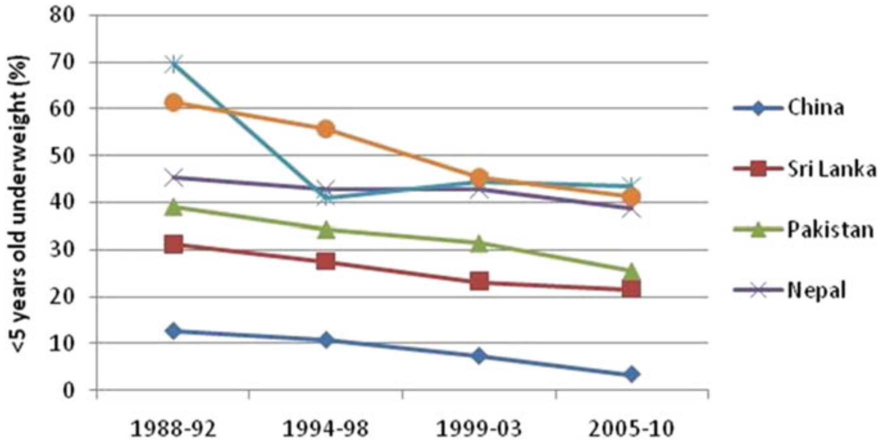


Fig. 9.2 <5-year-old's underweight as an indicator of food and nutritional security

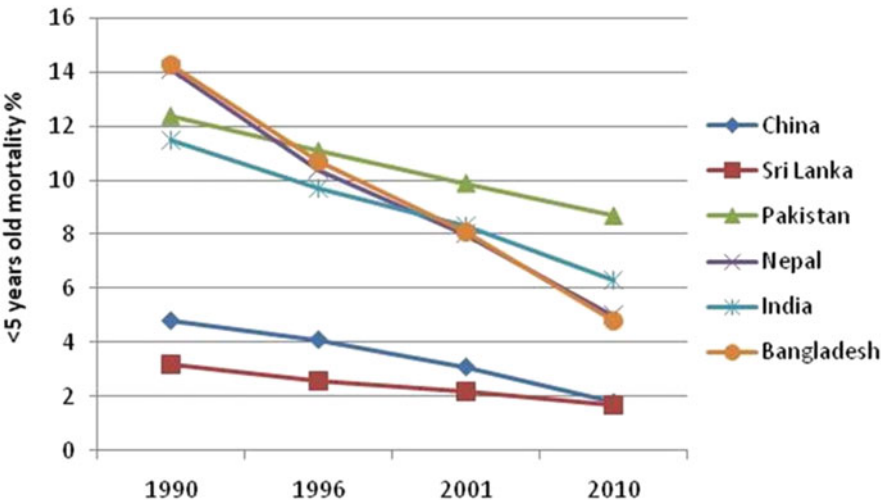


Fig. 9.3 <5-year-old's mortality as an indicator of food and nutritional security

potatoes' highest per hectare, per day production of edible dry matter, calorie, and vital nutrients provide a ray of hope.

9.2 Nutritional Value of Potato

Potato became popular over the period of time mainly due to its versatility in the way of cooking, viz. boiling, baking, deep-frying, etc. Potato, popularly known as the "vegetable king," is consumed in several forms of snacks such as chips, fries, and

Table 9.1 Recommended dietary allowances (RDA %) of some major nutrients provided by 100 g of boiled potatoes

Nutrient	Infant (up to 6 months with 5.4 kg body weight)		Adult man (moderately active with 60 kg body weight)	
	RDA	% of RDA provided by 100 g boiled potatoes	RDA	% of RDA provided by 100 g boiled potatoes
Energy (kcal/day)	108/kg	12	2875	2
Protein (g/day)	2/kg	18	60	3
Thiamine (mg/day)	55 μg/kg	34	1.4	7
Niacin (mg/day)	710 μg/kg	31	18	7
Pyridoxine (mg/day)	0.1	100	2	12
Folic acid (μg/day)	25	28	100	7
Ascorbic acid (mg/day)	25	70	40	42

Source: Singh et al. (2015)

dehydrated products. Potato is a primary or secondary source of food and nutrition for most of the undernourished households. In India, potatoes are utilized mainly in the form of vegetable and approximately 68.5% of potato harvest goes to domestic table consumption. Freshly harvested potatoes are almost 80% water and 20% dry matter. The dry matter majorly contains starch (60–80%). Potato protein content is comparable to cereals when compared on dry weight basis and much higher than other roots and tubers. Potato, being an excellent source of complex carbohydrates, dietary fibers, and vitamin C, also exhibits a variety of phytonutrients, such as carotenoids, flavonoids, caffeic acid, and unique tuber storage proteins, such as patatin. Along with ascorbic acid, potatoes also contain other vitamins such as thiamine, niacin, pantothenic acid, and riboflavin. Potato contains very low fat content, i.e., 0.1% on fresh weight basis. Since potatoes are prepared for consumption by boiling (with or without the skin), baking, or frying as their starch is not digestible in raw form, cooking method affects the nutrient composition of potatoes. The contribution made by consumption of 100 g of boiled potato to recommended dietary allowances (RDA) for various nutrients is compiled in Table 9.1.

9.2.1 Energy Value and Carbohydrates

Energy value of a boiled potato is lower (69 kcal energy per 100 g of weight) than a raw potato (80 kcal energy). Its low energy density in boiled form indicates that it is a good food for weight-conscious people. The energy value of potato is less than major food crops like rice, wheat, maize, and sorghum. The energy value of potato is much lower than other vegetables and food products (Fig. 9.4).

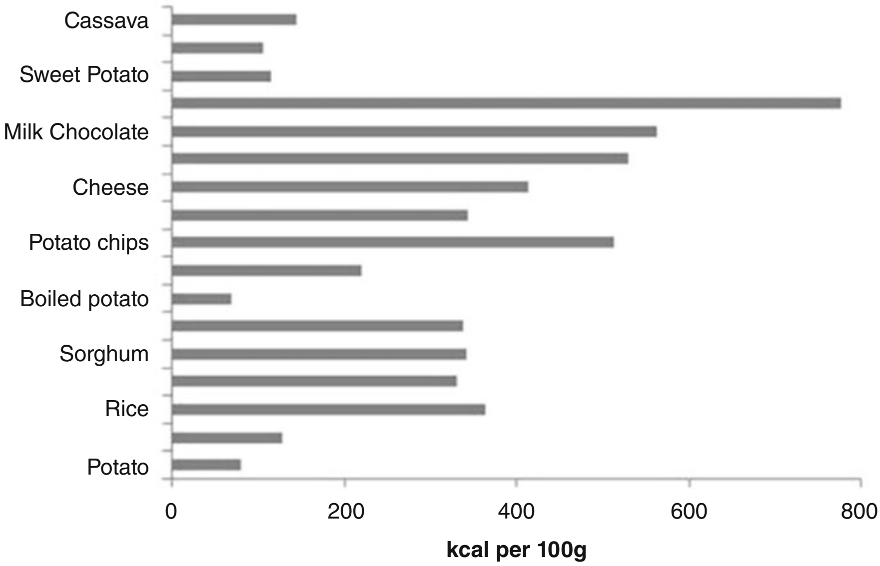
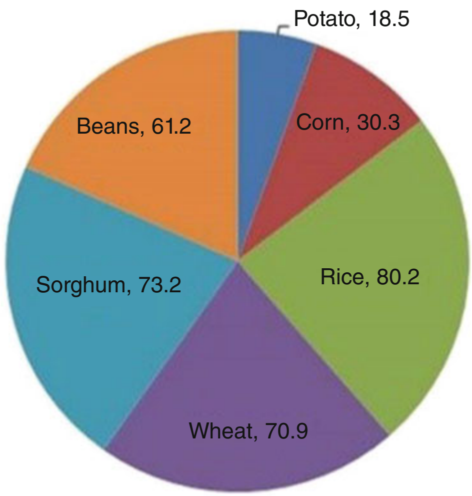


Fig. 9.4 Comparison of energy provided by raw potato and other foods (kcal/100 g edible portion)

Fig. 9.5 Carbohydrate content of raw potato vis-à-vis other plant foods (g/100 g edible portion)



Potatoes are an excellent source of complex carbohydrates that take longer time to break down into monosaccharides and hence result in long-lasting energy. The complex carbohydrates present in potato are important to a healthy diet. On an average, potato contains 14–16% of starch on fresh weight basis. The total carbohydrate content of potato is lower than cereals and other important crops such as wheat, rice, corn, sorghum, and beans (Fig. 9.5). Energy value of potato is dependent on the digestibility of starch. Potato starch digestibility is low in raw state that enhances considerably after processing. Sucrose, fructose, and glucose are the main sugars present in potatoes.

9.2.2 Protein and Amino Acids

On fresh weight basis, average protein content of potato is almost 2% and about 10% on dry weight basis. Though protein content is lower than wheat, rice, corn, sorghum, and beans, it is higher than other major root and tuber crops like sweet potato, yam, and cassava (Fig. 9.6). Potato tubers contain soluble protein, insoluble protein, and soluble nonprotein nitrogen. Among these, soluble protein contains considerable levels of essential amino acids and among these free amino acids are totally available for absorption. Adequate ratio of total essential amino acids to total amino acids and a balance among individual essential amino acid concentrations to meet the needs of infants and small children make potato protein superior to other foods (Table 9.2). Presence of all the essential amino acids in a good proportion in potato protein makes it a high-biological-value protein. Potato protein is superior to major cereals and even proteins of animal origin like milk and beef due to high biological value. Potato contains significant concentration of lysine because of which it can supplement diets which are limiting in lysine (Fig. 9.7a, b). Potato is a wholesome food because of its correct balance between net protein calories and total calories adequate for all age groups.

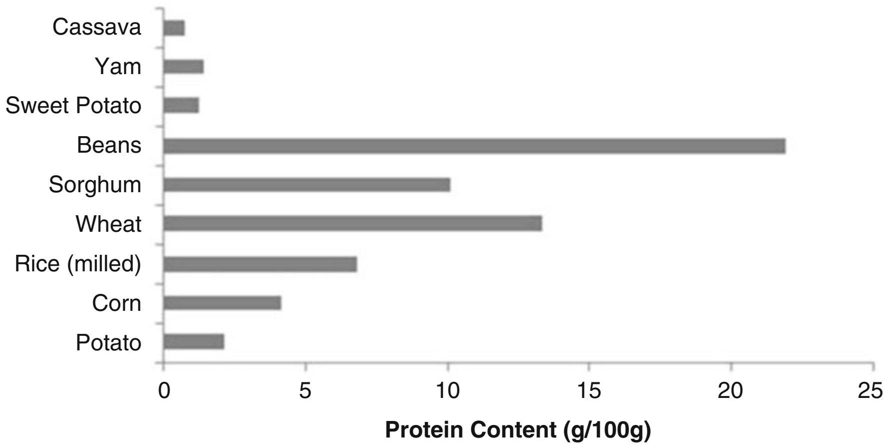


Fig. 9.6 Protein content of raw potato and other plant foods (g/100 g edible portion). (Source: Ezekiel et al. 1999)

Table 9.2 Essential amino acid content (mg/g N) of potato and other foods

Essential amino acids	Potato	Rice	Maize	Wheat	Soybean	Sweet potato	Yam	Cassava
Arginine	330	480	290	290	450	280	480	580
Histidine	100	130	160	130	150	90	120	110
Lysine	320	230	200	170	400	260	280	290
Tryptophan	100	80	40	70	80	110	70	80
Phenylalanine	270	280	290	280	300	270	300	180
Tyrosine	170	290	240	180	210	150	200	100
Methionine	90	150	120	90	80	100	100	50
Cystine	50	90	100	140	100	30	–	90
Threonine	220	230	280	180	240	280	220	200
Leucine	380	500	720	410	480	360	400	300
Isoleucine	270	300	240	220	320	290	230	250
Valine	310	380	300	280	320	380	290	240

Source: Singh et al. (2015)

9.2.3 Fat Content

Potatoes face friction due to the notion that they cause obesity and worsen diabetes. This is one of the major misconceptions linked to potato, since potatoes contain very little quantity of fat. Raw potatoes contain 0.1% fat on fresh weight basis, which is too low to have any negative impact on health. Potatoes' fat content is lower than major cereals like wheat, rice, maize, and also sorghum (Fig. 9.8). The little fat present in potato enhances potato palatability. Major proportion (i.e., nearly 60–80%) of this fat is composed of unsaturated fatty acids, linoleic acid being the predominant one. Presence of unsaturated fatty acids in higher proportion enhances the nutritive value of the potato fat. Potato is a healthy food for weight-conscious people because of its low energy density, provided that it is consumed without added fat. However, consumption of potatoes in fried form may certainly become a cause of concern due to its high energy density as processed potato products such as chips and French fries contain up to 40% fat (Ezekiel and Khurana 2003).

9.2.4 Potato Vitamins

Potato is known for its high vitamin C or ascorbic acid content as it contains 17–35 mg/100 g of tuber fresh weight. Vitamin C content in potato is higher than corn, wheat, rice, sorghum, beans, carrots, onion, and beetroot (Fig. 9.9). Potatoes itself can meet all the ascorbic acid requirements of the body when consumed in sufficient quantities. It is a water-soluble vitamin that acts as an antioxidant and hence helps to prevent cellular damage by scavenging free radicals. Potato provides protection against scurvy because of high ascorbic acid concentration. Vitamin C acts as an iron absorption enhancer in human body and also helps support the

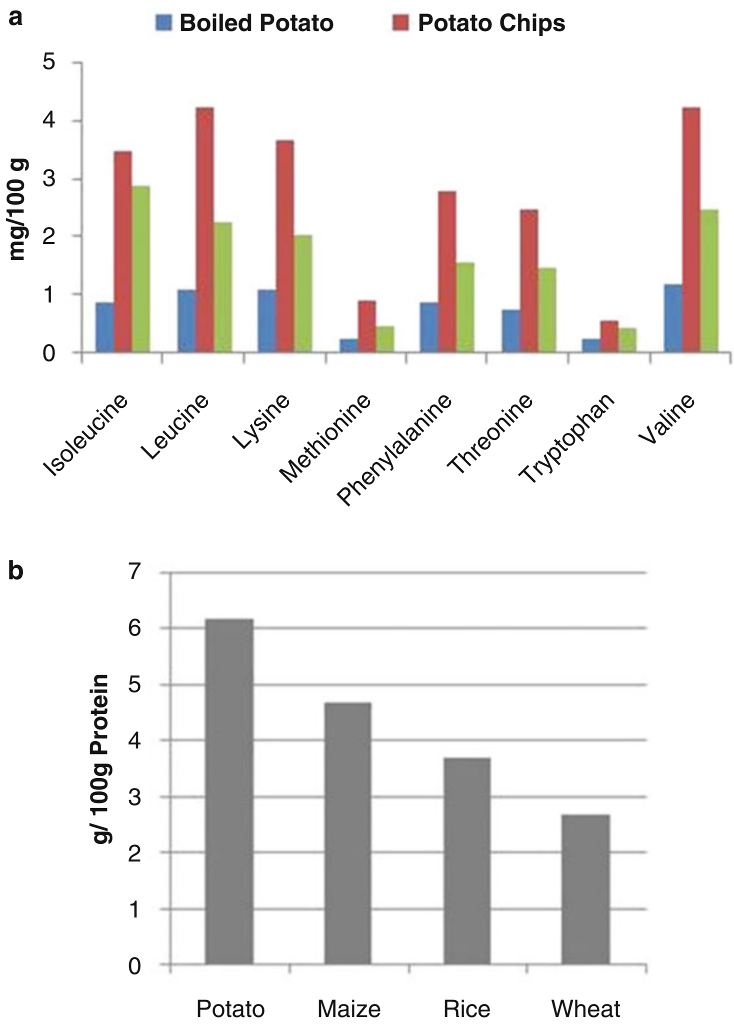


Fig. 9.7 (**a**) Amino acid content of potato and potato products; (**b**) lysine content (g/100 g protein) of potato and major cereal crops

immune system of the body. Storage, cooking, or processing reduces the ascorbic acid content of potatoes. Potato serves as a source of nutrition and particularly source of vitamin C to poorest of the poor due to its low cost and easy availability throughout the year.

Potato is also an important source of thiamine, niacin, pyridoxine, pantothenic acid (vitamin B5), riboflavin, and folic acid. B vitamins are water soluble, so it is recommended not to wash potatoes after peeling to avoid loss of vitamins. More than 20% daily value (DV) of vitamin C and vitamin B6 can be delivered by consumption of a small potato. Vitamin B complex helps the body to convert carbohydrates into

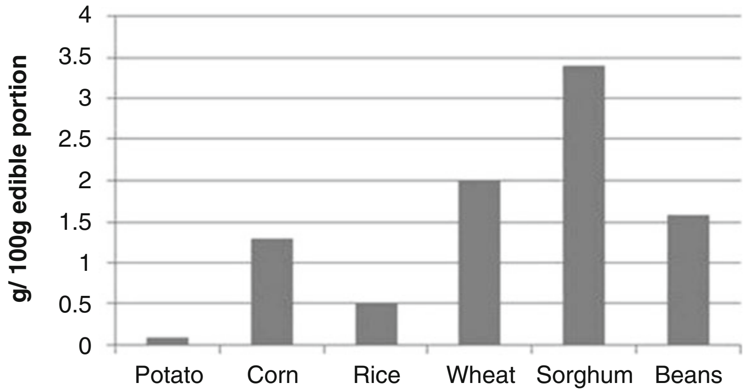


Fig. 9.8 Fat content of raw potato and other crops (g/100 g edible portion)

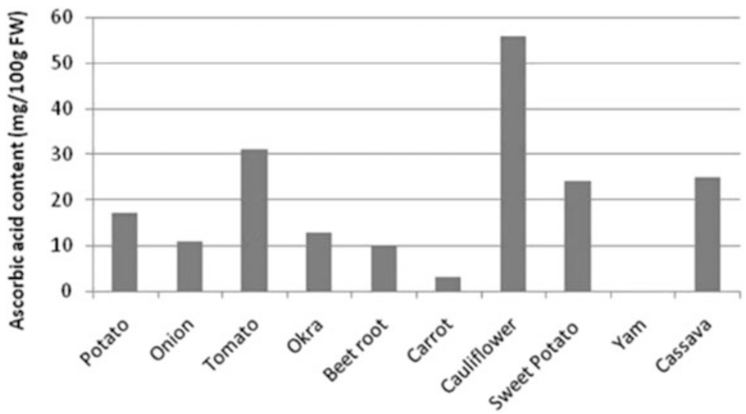


Fig. 9.9 Ascorbic acid content of potato and some other plant foods

glucose that are then used to produce energy. These vitamins are needed for healthy skin, eyes, hair, and liver; help the body utilize fats and protein; and are also required for proper functioning of the nervous system. Potatoes are an important source of thiamine, niacin, and pyridoxine. The role of potato as a source of some vitamins of B complex is vastly underestimated. A 100 g of freshly harvested potato contains 0.10 mg vitamin B1 (thiamine), 0.01 mg riboflavin, 1.5 mg niacin, 0.3 mg pantothenic acid, and 14 mg folic acid (Fig. 9.10). A 100 g of boiled potato (boiled with skin) can fulfill the daily requirement of thiamine, niacin, folic acid, and pantothenic acid. Among these vitamins, thiamine is required to release energy from carbohydrates and its insufficient intake leads to a disease called "beriberi" that affects the peripheral nervous system (polyneuritis) and the cardiovascular system. Riboflavin is used for treating riboflavin deficiency, muscle cramps, acne, burning feet syndrome, carpal tunnel syndrome, and blood disorders. Niacin plays a role in both DNA repair and production of steroid hormones in the adrenal gland.

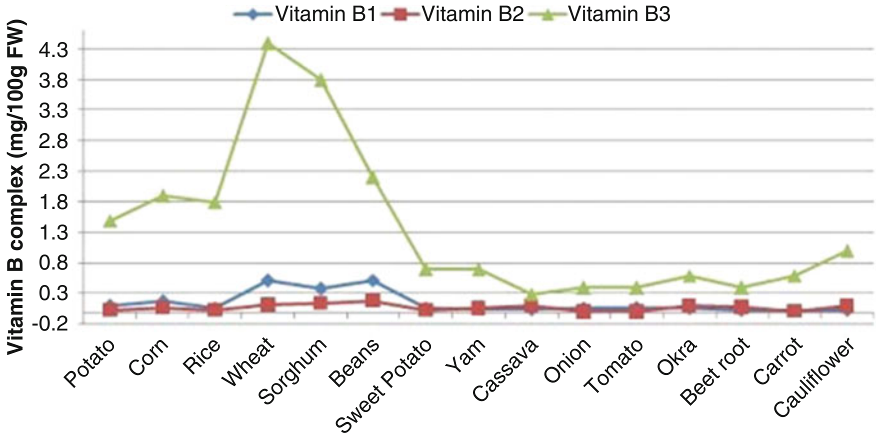


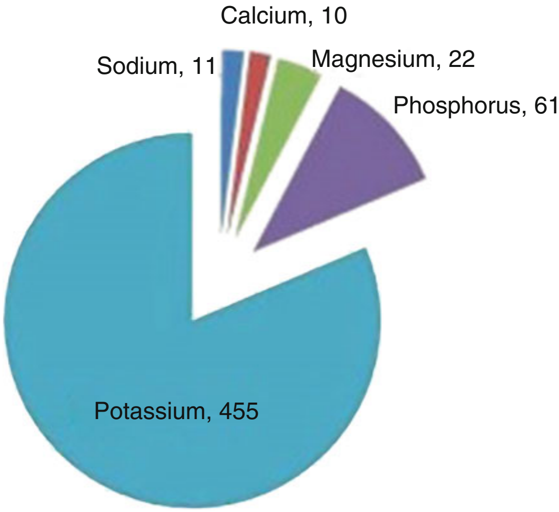
Fig. 9.10 Some of B-complex vitamins in raw potato and other plant foods

Pantothenic acid is an essential nutrient required to synthesize coenzyme-A (CoA), as well as to synthesize and metabolize proteins, carbohydrates, and fats. Pyridoxine also plays important roles in carbohydrate and protein metabolism, helps the body to synthesize nonessential amino acids required to synthesize body proteins, is also a cofactor for several enzymes involved in energy metabolism, and is required for the synthesis of hemoglobin. Folic acid is required to synthesize, repair, and methylate DNA and to act as a cofactor in biological reactions involving folate and helps to aid rapid cell division and growth such as in infancy and pregnancy. Folic acid is required to produce healthy red blood cells and prevent anemia in human body (Ezekiel and Khurana 2003).

9.2.5 Minerals

Potato contains some important minerals and trace elements. A 100 g of potato contains approximately 40–65 mg phosphorus, 247–455 mg potassium, 22 mg magnesium, and 11 mg sodium. Potato phosphorus is more assimilable than phosphorus in other food crops because of the relatively lower content of phytic acid in potato. Phosphorus, calcium, iron, and zinc bioavailability to human body is enhanced due to lower phytic acid content of potato (Fig. 9.11). Potatoes are not included in the diet of patients with renal failure because of its high potassium content. Potatoes contain iron content comparable to most of the other vegetables. Cooked potato (100 g) can supply between 6% and 12% of daily iron requirement for children or adults. High ascorbic acid content of potato enhances the bioavailability of nonheme form of iron. Potatoes mixed with other food can also increase the bioavailability of iron from other foods due to high ascorbic acid content. Iron availability from potato is higher compared to kidney beans, wheat flour, and bread, with the reason being that the high proportion of iron from potato is soluble.

Fig. 9.11 Mineral content of raw potato (mg/100 g edible portion)



Because of its high magnesium content, potato can be consumed with foods low in magnesium. Magnesium content of milk is one-fifth to one-tenth of potato; hence, potato is of superior quality than milk. Milk being rich in calcium and potato being a good source of magnesium become a healthy food combination. Though zinc content of potato is low, its availability is high due to the low phytic acid content of potatoes. Potato can supply a part of daily requirements of trace elements such as manganese, copper, molybdenum, and chromium. Potato can also provide traces of boron, bromine, iodine, aluminum, cobalt, and selenium. A small potato can provide 10% DV of folate, magnesium, manganese, and phosphorus. Potato, being in reach of low-income groups, can play an imperative role in "hidden hunger" eradication.

9.2.6 Dietary Fiber

Potatoes' cellulose, pectin, and pectin-associated substances are higher compared to cereal bran (Ezekiel and Khurana 2003). Raw potato tuber contains 1–2 g/100 g fresh weight dietary fiber content. Unpeeled potatoes exhibit more dietary fibers than peeled potatoes (Fig. 9.12). Potatoes must be consumed along with peel to enhance dietary fiber intake. Pectic substances constitute more than half the dietary fiber content that improves the quality of potato dietary fiber and thus help to lower cholesterol levels. One medium-sized unpeeled potato contributes 2 g of fiber or 8% of the DV of dietary fiber. Dietary fiber, being a complex carbohydrate, cannot be digested and absorbed in the bloodstream. Dietary fiber plays an important role in improving blood lipid levels, regulating blood glucose, and increasing satiety, which may help in weight management. The major components of dietary fiber are non-starch polysaccharides (NSPs), resistant starch, lignin, and nondigestible oligosaccharides. Resistant starch is known as "starch and starch degradation

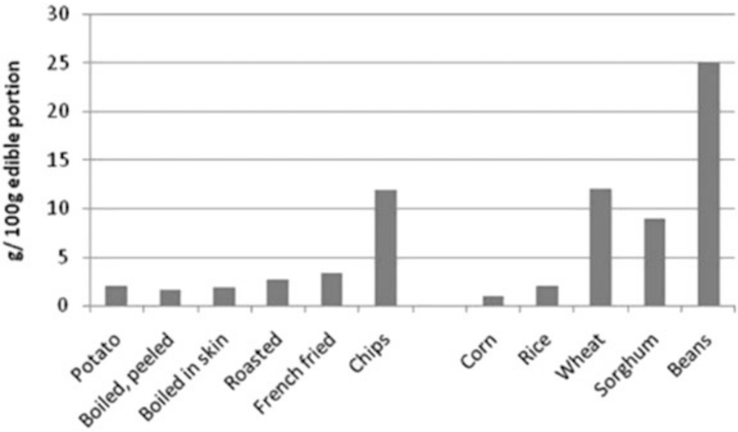


Fig. 9.12 Dietary fiber content of raw potato and other foods (g/100 g edible portion)

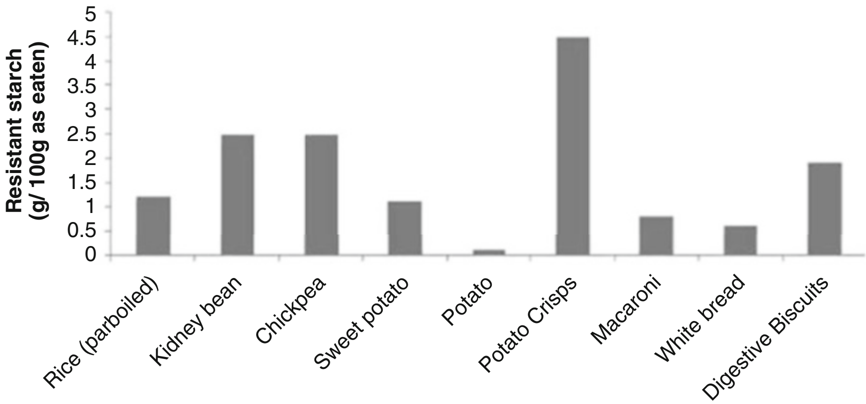


Fig. 9.13 Resistant starch content of different food materials

products that escape digestion in the small intestine of healthy individuals." Resistant starch acts like fibers and is present naturally in foods such as legumes, bananas, potatoes, and some unprocessed whole grains. Resistant starch content is approximately 1.5–2% in cooked and cooled tubers (Raigond et al. 2014). Natural resistant starch is generally insoluble and fermented in the large intestine and acts as a prebiotic fiber. Resistant starch appears to exert beneficial effects within the colon by releasing short-chain fatty acids. The resistant starch formation in potatoes is highly dependent upon processing and storage conditions. Cooking and then cooling potatoes lead to nearly a twofold increase in resistant starch (Fig. 9.13). Even processed potatoes such as potato flakes retain a significant amount of resistant starch that confers health benefits. Resistant starch is a third type of dietary fiber, because it can deliver some of the benefits of insoluble fiber and some of the benefits of soluble fiber.

9.2.7 Antioxidants

Potatoes contain a number of small molecules that are generally secondary metabolites, many of which are beneficial phytonutrients such as phenols, flavonoids, kukoamines, anthocyanins, and carotenoids. Colored potatoes contain a high concentration of natural anthocyanin pigments and are also a powerful source of antioxidant micronutrients. Potato antioxidants play an important role in immune function and disease prevention. Yellow-colored potatoes have high carotenoid content, which mainly contains lutein, zeaxanthin, violaxanthin, and antheraxanthin (Ah-Hen et al. 2012). Potato carotenoids are primarily oxygenated carotenoids, which are also known as xanthophylls. Purple-colored potatoes protect against cardiovascular disease, while yellow pigmented potatoes enhance immune response (Kaspar et al. 2013). β-Carotene has been detected only in trace amounts in colored potatoes. The orange color of the tuber flesh is due to zeaxanthin, whereas the yellow color is due to lutein. Generally, high phenolic contents such as anthocyanin are present in dark-colored potatoes; however, white/cream potatoes also contain phenolics to some extent.

9.2.8 Novel Health-Promoting Compounds

Per capita consumption of potato is high compared to other vegetables in most countries; however, their nutritional value is always underestimated. Few misconceptions related to their role as a contributor to obesity and diabetes development increase friction towards their consumption. Presence of relatively higher concentrations of health-promoting compounds to combat chronic disease development is vastly underestimated in case of potatoes. Studies have shown the potential of potatoes to confer several health benefits in human cell culture, experimental animals, and human clinical studies, and their anticancer, hypocholesterolemic, anti-inflammatory, anti-obesity, and antidiabetic potential has also been reported. For treatment of diabetes, several pharmacological agents such as sulfonylureas, biguanides, α-glucosidase inhibitors, thiazolidinediones, and meglitinide are used due to their different modes of action (Raigond et al. 2018a). Biguanide and related compounds (BRCs) are a class of compounds that include guanidine, galegine, metformin, phenformin, urea, biuret, and L-arginine and are known to enhance insulin sensitivity, decrease glucose absorption, and hence reduce hyperglycemia. Among all the biguanide and related compounds, metformin is quite popular and used as the first-line drug of choice to treat type 2 diabetes. Potatoes have been reported to contain compounds such as α-glucosidase inhibitors and biguanide and related compounds (BRCs). Perla and Jayanty (2013) were the first to report the presence of BRCs in potatoes with a concentration of 7.05 μg/g. Later, Raigond et al.

(2018a) quantified BRCs from vegetables and fruits including potato. BRCs in vegetables ranged from 0.20 to 3.28 mg/g FW and in fruits from 0.17 to 1.91 mg/g FW. Potato contained 0.56 mg/g FW BRCs, and consumption of BRCs through potato is almost 29.36 mg/day when calculated on the basis of per capita consumption of potato in India, i.e., 19 kg/person/year. Potato peel contained almost double concentration of these compounds than flesh (Raigond et al. 2016). α-Glucosidase, a membrane-bound enzyme present in the epithelium of small intestine, facilitates the absorption of glucose by small intestine by catalyzing the hydrolytic breakdown of oligosaccharides to absorbable monosaccharides. Inhibition of this enzyme can inhibit the starch hydrolysis and hence can help in decreasing the postprandial enhancement in blood glucose. Raigond et al. (2016, 2017) reported the presence of α-glucosidase inhibitors in Indian potatoes. Among 46 potato varieties, the inhibitory activity was present in 14 potato varieties and the in vitro inhibitory activity ranged from 0% to 52.8%. Their reports showed the potential of indigenous potato varieties to manage diabetes, particularly type 2.

Angiotensin-converting enzyme (ACE) converts the angiotensin I (inactive decapeptide) to angiotensin II (a potent vasoconstrictor), and bradykinin (a hypotensive peptide) to inactive components, which in turn increases blood pressure. High ACE activity increases the concentration of angiotensin II leading to hypertension. These inhibitors are used as first-line treatment of hypertension. Plant parts with high antioxidative potential act as ACE inhibitors. Raigond et al. (2018b) reported the presence of ACE inhibitors in Indian potatoes. The ACE inhibitory activity ranged from 0% to 56.23% in tested samples. Out of tested 25 Indian varieties, ACE inhibitory activity was recorded in six varieties. All these reports showed that the Indian potato varieties contain antidiabetic and antihypertensive compounds. Such studies will help to improve the image of potatoes and reduce the friction towards its consumption.

9.3 Antinutrients: Glycoalkaloids, Acrylamide, and Phytate

Potatoes exposed to sunlight form alkaloids called “glycoalkaloids,” the main constituents of which are α-chaconine and α-solanine. Potatoes generally contain less than 5 mg solanine per 100 g fresh weight, which is much less than the safety limit of 20 mg/100 g. Glycoalkaloid content in potato is so low that it is not even perceptible by taste. However, green potatoes might contain higher glycoalkaloids resulting in health threats and therefore are not recommended for consumption. Potatoes have much lower glycoalkaloid content with uneven distribution, where higher levels are present in the periderm and cortex, decreasing markedly towards the pith. Most of the glycoalkaloids (80%) are present in the outer layer and therefore can be easily removed.

Acrylamide is classified as a group 2A carcinogen, that is, probable human carcinogen, and has been reported in common foods, such as potato chips, French fries, cookies, cereals, and bread, which are prepared at a temperature of over 120 °C. Preliminary findings of acrylamide in some fried and baked foods by Swedish researchers shocked the food safety world. The food items were potato crisps and French fries with acrylamide level of 30–2300 μg/kg. Since then, much emphasis has been given on the quantification of acrylamide in fried and baked products. Acrylamide has probably been part of our diet since man first started cooking; however, because of safety concerns, there is need to reduce the levels of acrylamide in foods. Acrylamide is formed due to Maillard reaction that occurs between amino acid (asparagine) and reducing sugars (fructose and glucose). Acrylamide content in fried products prepared from Indian potato processing varieties, viz. Kufri Chipsona-1, Kufri Chipsona-2, Kufri Chipsona-3, Kufri Himsona, and Kufri Frysona, ranged from 63 to 101 μg/kg.

9.4 Nutritional Value of Potato Products

Potatoes are processed into several forms such as fried, pre-fried and frozen fries, baked, dehydrated, and other miscellaneous products such as organic acids, alcohol, boiled and peeled, mashed, and canned. With the technological interventions, potato processing is growing rapidly globally, and trend of potato utilization is shifting from fresh consumption to processing and value addition. Dehydrated potato flakes share a major proportion of the global market as they are used in the preparation of mashed potato products and fabricated products and as an ingredient in several fried snacks. Similarly, potato flour is also gaining popularity due to its use in meat mixtures and as a thickener in gravies and soups. North America and Europe dominate the global chips market accounting for almost two-thirds of the total global demand. Even the markets of India, China, and Russia are also witnessing promising growth rates. With the economic development, the incidence of many cardiovascular diseases, cancer, and diabetes is rapidly increasing worldwide. Therefore, consumers are now inclining towards fortified potato chips. In the present scenario, it is pertinent to popularize the nutritional value of potato products. The nutritional significance of a product depends on several factors, such as nutritional quality of the commodity, processing methods, and temperatures during processing.

9.4.1 Nutritional Value of Most Popular Processed Potato Products

9.4.1.1 Nutritional Value of Potato Chips

Chips are often considered as “junk food” and lead to obesity (Fig. 9.14). Due to ever-increasing health awareness, many big processing players have introduced not only low-oil chips such as baked but also healthier variants of potato chips without any added artificial flavors or colors and with non-GMO ingredients. Nutritionally, potato chips are high-fat and high-energy food. A 2000-calorie reference diet showed that 100 g of plain salted potato chips can provide up to 27% of recommended daily value (RDV) for energy, 58% of RDV for fat, 13% of RDV for protein, 17% of RDV for carbohydrate, 18% of RDV for dietary fiber, and 3.9 g of RDV for ash (USDA 2019). Among this, about 37% of energy comes from

Fig. 9.14 Potato chips

carbohydrates, more than 60% from fat, and about 3.3% from proteins present in the chips. Potato chips contain 3–11 g/100 g of saturated fat accounting for up to 55% of RDV. The predominant fatty acids in potato chips include palmitic acid, stearic acid, myristic acid, and some part as lauric acid. One hundred grams of potato chips can provide 9.8 g of monounsaturated fatty acids, 12.2 g of polyunsaturated fatty acids, 190 mg of omega-3 fatty acids, and 11,980 mg of omega-6 fatty acids, depending on the type of frying oil used (USDA-SR Legacy 169677 2019). Potato chips contain 5.6–6.6% protein that is more than thrice of fresh potatoes. Though most of the proteins denature at temperatures higher than 100 °C, it helps to improve the digestibility of proteins and enhance the nutritional value of chips, which is desirable from the nutritional point of view. Therefore, potato chips have better digestibility than fresh potatoes. However, during frying, some undesirable changes also occur leading to losses of amino acids up to 7%. Though fresh potatoes provide almost 126 mg of lysine, plain salted chips contain 424 mg of lysine per 100 g of weight (USDA-SR Legacy 170032 2019). Potato chips contain more tryptophan (108 mg per 100 g weight) than fresh potatoes (32 mg per 100 g weight) (USDA-SR Legacy 169677 2019). Similarly, cystine is also more in potato chips (89 mg per 100 g weight) than fresh potato (26 mg per 100 g weight). Serine is almost 3.37 times higher and methionine is almost 3.33 times higher in potato chips than fresh potatoes. Along with these, many other essential amino acids are also 3.35–3.42 times higher than fresh potatoes. One hundred grams of potato chips can provide 419 mg leucine, 153 mg of histidine, 283 mg isoleucine, 253 mg threonine, 310 mg phenylalanine, and 392 mg valine. Similarly, the nonessential amino acid content of potato chips is also 3.34–3.42 times higher than fresh potatoes. One hundred grams of potato chips can provide 214 mg of alanine, 321 mg of arginine, 1706 mg of aspartic acid, 1170 mg of glutamic acid, 251 mg of glycine, 251 mg of proline, and 259 mg of tyrosine per 100 g weight (USDA-SR Legacy 169677 2019). The total dietary fiber in potato chips prepared by continuous process was 2.5% and in kettle chips was 3.39%. Baking is reported to increase the total dietary fiber with more proportion of soluble dietary fiber (Mullin and Smith 1991). Plain salted potato chips can provide 2.2–3.4% dietary fibers that is at par with fresh potatoes with skin (USDA-SR Legacy 169677 2019). Though raw potatoes are a good source of vitamin C, potato chips have more dietary vitamin C due to the rapid dehydration of potato tubers at the time of frying. Potato chips contain up to 18.6–21.6 mg/100 g of vitamin C. Frying results in a 30–50% loss in vitamin C due to heat sensitivity (Tian et al. 2016). Kondo et al. (2012) reported vitamin C from mashed potatoes and potato chips to be more bioavailable in the intestine, leading to increased plasma levels after consumption. USDA database showed that different variants of potato chips provide up to 3.9–7.15 mg/100 g niacin. Fresh potato chips can provide 6.7–10.5 mg vitamin E/100 g as alpha-tocopherols. Potato chips provide more vitamin B6 (0.40–0.64 mg/100 g) than fresh potatoes (0.3 mg/100 g) (USDA-SR Legacy 169677 2019). Similarly, folate is also more in potato chips (29.0–75.0 μg folate/100 g) than fresh potatoes (16 μg/100 g) (USDA Standard Reference legacy data). Potato chips exhibit 0.78–1.0 mg pantothenic acid per 100 g of chips. Finglas and Faulks (1984) reported deep fat frying to cause minimal changes in the mineral content of the potato. Plain salted potato chips provide more minerals than fresh potatoes. One hundred grams of plain salted potato chips provide 17–31 mg of calcium, 1.02–1.49 mg of iron, 49–81 mg of magnesium, 120–201 mg of phosphorus, 983–1380 mg of potassium, 235–633 mg of sodium, 0.77–1.35 mg of zinc, 0.059–0.378 mg of copper, and 0.335–0.57 mg of manganese (USDA-SR Legacy 169677 2019).

9.4.1.2 Nutritional Value of French Fries

Jack Simplot in the USA was the first to start the production of frozen French fries. French fries are the second highest popular potato products after chips. French fries are produced in three major forms at a commercial scale, viz. (1) deep-frozen completely fried strips, which just require oven heating; (2) deep-frozen partially fried strips, which require additional frying before eating; and (3) refrigerated partially fried strips, which have a short shelf life and need additional frying (Lisinska and Leszczynski 1989).

Being deep fried in oil, French fries are also fat-rich high-energy food (Fig. 9.15). French fries can provide 312 kcal of energy, 3.43 g protein, 14.73 g of fat, 41.44 g

Fig. 9.15 French fries

carbohydrates, 3.8 g total dietary fiber, 0.3 g sugars, and 1.85 g per 100 g of ash. French fries contain 2.34 g saturated fat, 5.97 g monounsaturated fatty acids, 5.40 g polyunsaturated fatty acids, 0.06 g trans-fatty acids, 168 mg total omega-3 fatty acids, and 2831 mg total omega-6 fatty acids (USDA-SR Legacy 170698 2019). However, this composition can vary depending upon the quality of oil used and frying time and temperature. Vitamin content of fried products depends on the vitamin content of frying oil used for processing. French fries contain 1.3–6.8 mg vitamin C, 0.14–0.19 mg thiamine, 2.06–3.66 mg niacin, 0.03–0.06 mg riboflavin, 0.28–0.44 mg vitamin B6, 0.47–0.7 mg pantothenic acid, 8–64 μg total folate, and 6.4–16 μg vitamin K (phylloquinone) per 100 g of serving. French fries provide 0.91–2.55 mg of alpha-tocopherol, 0.02–0.12 mg of beta-tocopherol, 1.03–8.4 mg of gamma-tocopherol, and 0.28–2.68 mg of delta-tocopherol, and the content depends upon the frying medium used (USDA-SR Legacy 170698 2019). However, French fries are not a good source of vitamin A, vitamin B12, and vitamin D. Mineral content of a product is dependent on the mineral content of the commodity used as raw material. French fries contain 451–675 mg potassium, 0.63–1.07 mg iron, 115–363 mg sodium, 12–23 mg calcium, 25–40 mg magnesium, 88–153 mg phosphorus, 0.39–0.73 mg zinc, 0.072–0.212 mg copper, 0.183–0.343 mg manganese, and 0.4–1.2 μg selenium per 100 g serving (USDA-SR Legacy 170698 2019). French fries are a good source of protein. The protein content in French fries is 3.43 g that can provide 6.13% of RDA for adult males and 7.46% of RDA value for adult females (DRI 2006). French fries are a source of both essential and nonessential amino acids. Nonessential amino acids, viz. alanine (119 mg/100 g), arginine (179 mg/100 g), aspartic acid (765 mg/100 g), cysteine (33 mg/100 g), glutamic acid (586 mg/100 g), glycine (103 mg/100 g), proline (126 mg/100 g), serine (125 mg/100 g), and tyrosine (87.0 mg/100 g), are present in French fries. French fries contain essential amino acids, viz. histidine (66 mg/100 g), isoleucine (120 mg/100 g), leucine (188 mg/100 g), lysine (225 mg/100 g), methionine (58 mg/100 g), phenylalanine (206 mg/100 g), threonine (120 mg/100 g), tryptophan (38 mg/100 g), and valine (178 mg/100 g).

9.4.1.3 Nutritional Value of Sticks and Shreds

Nutritional value of potato sticks and shreds is similar (Fig. 9.16). Potato sticks provide 522 kcal of energy, which accounts for 26% of DV for a 2000-calorie reference diet. Out of this, carbohydrates contribute 41% energy, fat 55%, and proteins 4%. Potato sticks contain 53.3 g of total carbohydrates that accounts for 18% DV and 3.4 g of dietary fiber that fulfills 14% DV for 2000-calorie diet. Fat content of potato sticks is around 34.5%, where depending on the frying medium used, 26% fat is contributed by saturated fatty acids, 18% by monounsaturated fatty acids, and 52% by polyunsaturated fatty acids (USDA-SR Legacy 168854 2019). Quality of frying oil determines the vitamin content of sticks and shreds. Potato sticks contain 47.3 mg vitamin C (79% of DV for a 2000-calorie reference diet), 9.1 mg vitamin E (43% DV), 0.1 mg thiamine (6% DV), 22.1 μg vitamin K (28% DV), 0.1 mg riboflavin (7% DV), 4.8 mg niacin (24% DV), 0.3 mg vitamin B6 (16% DV), 40 μg folate (10% DV), and 0.4 mg pantothenic acid (4% DV) per 100 g

Fig. 9.16 Potato shreds

serving. Potato sticks contain minerals, viz. potassium (1237 mg, 35% DV), calcium (18 mg), iron (2.3 mg, 13% DV), magnesium (64 mg, 16% DV), phosphorus (172 mg, 17% DV), sodium (250 mg, 10% DV), zinc (1.0 mg, 7% DV), copper (0.3 mg, 16% DV), manganese (0.4 mg, 21% DV), and selenium (8.1 μg, 12% DV) per 100 g serving (DRI 2006).

9.4.2 Nutritional Value of Frozen Potato Products

Some potato products are processed and frozen, which need minimal preparation, generally frying before consumption. These products are highly convenient and flexible. Frozen products such as French fries, shapes, hash brown, battered/cooked, mashed, twice baked, topped/stuffed, and other frozen potatoes are available in the market.

9.4.2.1 Nutritional Value of Unsalted Frozen French-Fried Potatoes

Though French fries are high-calorie food due to deep-frying in oil, they contain some beneficial nutritional compounds such as minerals and vitamins. Carbohydrates, fat, and some proteins are major constituents of French fries. French fries contain 150 kcal energy (8% DV for a 2000-calorie reference diet), out of which 66% calories are contributed by carbohydrates, 28% by fat, and 6% by proteins. French fries contain 24–25% total carbohydrates, out of which 7–9% are contributed by dietary fibers, 70–75% by starch, and rest by simple sugars. Frozen fries contain 3.3–6.1% fat, out of which 19–20% is supplied by saturated fatty acids, 63–65% by monounsaturated fatty acids, and 6–7% by polyunsaturated fatty acids. Frozen fries contain 1.98–2.41% protein content. Ascorbic acid in French fries ranged from 10.5 to 24.5 mg per 100 g serving. Based on frying oil, frozen fries may provide 0.05–0.16 mg of alpha-tocopherol, 0.1–0.6 mg of gamma-tocopherol, and

0.24–0.76 mg of delta-tocopherol. Other vitamins such as thiamine (0.64–1.28 mg), riboflavin (0.03–0.103 mg), niacin (1.86–2.24 mg), pantothenic acid (0.394–0.577 mg), vitamin B6 (0.157–0.203 mg), total folate (21–42 μg), and vitamin K (1.6–2.8 μg per 100 g serving) are also present in frozen fries. Among the minerals, frozen fries contain potassium (385–433 mg, 12% DV), calcium (8–11 mg), iron (0.54–0.77 mg), magnesium (20–23 mg), phosphorus (70–103 mg), sodium (21–23 mg), zinc (0.33–0.37 mg), copper (0.71–0.127 mg), and manganese (0.143–0.179 mg per 100 g) serving (USDA-SR Legacy 170523 2019).

9.4.2.2 Nutritional Value of Frozen Potato Wedges

Potato wedges are wedge-shaped potato slices/cuts coated with some seasoning and herbs. Potato wedges provide 123–129 kcal energy, out of which 73% of the energy value comes from carbohydrates, 16% from fats, and 8.7% from proteins. Frozen wedges contain 25.5% carbohydrates, and the fat content ranges between 2.0% and 2.5%. Frozen wedges also contain omega-6 fatty acids (102 mg of total per 100 g serving). Frozen wedges contain 2.7% protein, which fulfills 5% of the DV for a 2000-calorie reference diet. Frozen wedges contain vitamin C (11.2 mg, 19% of daily value), thiamine (0.1 mg), niacin (1.5 mg), and vitamin B6 (0.4 mg per 100 g serving). Minerals include calcium (15 mg), iron (0.1 mg), magnesium (19 mg), phosphorus (87 mg), potassium (394 mg), sodium (49 mg), and zinc (0.4 mg) (USDA-SR Legacy 168443 2019).

9.4.2.3 Nutritional Value of Frozen Potato Puffs

Potato puffs provide 175 kcal of energy, out of which 59% of the calories are contributed by carbohydrates, 37% by fats, and rest by proteins. Potato puffs exhibit 24.8–26% total carbohydrates, 7.3% of which are contributed by dietary fibers, 76.15% by starch, and rest by simple sugars. Potato puffs contain 7.37–10.54% fat content (after preparation), 21–25 mg omega-3 fatty acid, and 360–365 mg omega-6 fatty acid per 100 g of frozen unprepared potato puff. The protein content of the puffs ranges between 1.62% and 2.25% and contains amino acids, viz. aspartic acid (371 mg), glutamic acid (320 mg), leucine (151 mg), lysine (133 mg), arginine (128 mg), valine (122 mg), and serine (100 mg) per 100 g serving. Frozen potato puffs provide vitamin A (4 IU), beta-carotene (3 μg), lutein + zeaxanthin (15 μg), vitamin C (7.5 mg), alpha-tocopherol (0.2 mg), gamma-tocopherol (1.1 mg), delta-tocopherol (1.1 mg), vitamin K (3.4 mg), thiamine (0.1 mg), niacin (1.4 mg), vitamin B6 (0.1 mg), folate (35 μg), and pantothenic acid (0.3 mg). Frozen puffs contain a relatively higher amount of sodium (257–483 mg/100 g) than fresh potatoes. Potato puffs contain minerals such as calcium (9–15 mg), iron (0.4–0.6 mg), magnesium (13–20 mg), phosphorus (49–88 mg), potassium (190–354 mg), zinc (0.18–0.35 mg), copper (0.049–0.095 mg), and manganese (0.093–0.174 mg) (USDA-SR Legacy 170047 2019).

9.4.2.4 Nutritional Value of Hash Brown Potatoes

Mature white potatoes are washed, peeled, sorted, trimmed, blanched, may or may not be fried, shredded or diced or chopped, and then frozen to assure a wholesome frozen product. Unprepared frozen plain hash brown potatoes exhibit 82 kcal energy and 8–17% total carbohydrates. They contain 0.6% total fat and also contain 64 mg omega-3 fatty acids and 201 mg omega-6 fatty acids. The protein content of these potatoes ranges between 2.0% and 2.5%. Hash brown potatoes provide aspartic acid (478 mg), glutamic acid (322 mg), leucine (124 mg), lysine (110 mg), valine (105 mg), arginine (98 mg), threonine (94 mg), isoleucine (89 mg), phenylalanine (88 mg), glycine (75 mg), serine (74 mg), alanine (71 mg), proline (66 mg), and tyrosine (52 mg per 100 g serving). Frozen hash brown potatoes are a good source of vitamin C (8.2 mg per 100 g serving) and also provide niacin (1.7 mg per 100 g serving), pantothenic acid (0.3 mg per 100 g serving), and thiamine, vitamin B6, and folate in small amounts. Hash brown potatoes are a good source of potassium (285 mg/100 g) and contain low concentration of sodium (22 mg/100 g). A 100 g serving of hash brown potatoes can provide calcium (10 mg), iron (1.0 mg), magnesium (11 mg), phosphorus (47 mg), zinc (0.2 mg), copper (0.1 mg), and manganese (USDA-SR Legacy 170043 2019).

9.4.2.5 Nutritional Value of Whole, Boiled Potatoes

Boiled potatoes contain 65 kcal of energy, and about 90% of this energy is contributed by carbohydrates, 1.6% by fats, and 8.4% by proteins. Boiled potatoes exhibit 14.5% total carbohydrates and 1.4% dietary fiber. Boiled potatoes contain almost nil fat content (0.1%) and almost 2.0% protein. Boiled frozen potatoes can provide aspartic acid (483 mg), glutamic acid (331 mg), tryptophan (31 mg), threonine (72 mg), isoleucine (80 mg), leucine (119 mg), lysine (120 mg), methionine (31 mg), cysteine (25 mg), phenylalanine (88 mg), tyrosine (73 mg), valine (111 mg), arginine (91 mg), histidine (43 mg), alanine (61 mg), glycine (59 mg), proline (71 mg), and serine (86 mg per 100 g serving). Boiled potatoes contain 9.4 mg ascorbic acid per 100 g serving (16% DV on a 2000-calorie reference diet). Boiled potato can provide thiamine (0.1 mg), niacin (1.3 mg), vitamin B6 (0.2 mg), total folate (8 μg), and pantothenic acid (0.3 mg per 100 g serving). Boiled potatoes are rich in potassium (287 mg/100 g) and also contain calcium (7 mg), iron (0.8 mg), magnesium (11 mg), phosphorus (26 mg), and sodium (20 mg/100 g) (USDA-SR Legacy 170049 2019).

9.5 Conclusion

Report of the International Food Policy Research Institute "Global Hunger Index 2012" showed some serious concerns about food security in India. To conquer such grave and distressing situations, potato provides a way out to deal with the problem of hunger and provides food and nutritional security. Potato can be a perfect replacement for other cereals due to its high nutritional value and high production and productivity. Potato is a nutritious and wholesome food. Its low energy density is beneficial when eaten without much added fat. Potatoes contain high-quality protein rich in essential amino acids. It is a rich source of vitamin C and is far superior in this respect to most other vegetables and cereals. Substantial quantities of some of the B group vitamins are also present in potato. Potatoes contain many minerals and trace elements and concurrently are low in fats. Moreover, among the major food crops, bioavailability of minerals is potentially high in potatoes because of the presence of high concentrations of micronutrient absorption enhancers such as ascorbate. Also, low content of absorption inhibitors such as phytate and oxalate further improves the bioavailability of minerals from potato. Hence, potato as such is a nourishing food and anyone can live by eating potatoes alone. With ever-increasing population, potatoes are destined to be very crucial for providing food and nutritional security to populations in the developing countries including Indian masses.

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10 Antioxidants and Health Benefits of Brinjal

Pranab Hazra

Abstract

Brinjal or eggplant (*Solanum melongena* L.) is a warm-weather crop and widely cultivated in tropical and subtropical regions of the world. It is the fifth most economically important solanaceous crop in the world after potato, tomato, pepper and tobacco. In India, it ranks fourth in total vegetable production after potato, onion and tomato. Brinjal has a very low caloric value and is considered among the top ten vegetables for its high content of protein; various vitamins; minerals like iron, calcium, potassium and magnesium; dietary fibre; and different bioactive phyto-chemicals which are desirable for body growth. However, few studies have investigated compounds beyond phenolic acids and antioxidant capacity although more than 2500 indigenous cultivars are available in India. Metabolomics and metabolic profiling should be used for the discovery of various bioactive compounds including primary metabolites, and new breeding priorities and strategies need to be framed aiming at improving nutraceutical and pharmaceutical value of brinjal apart from improving yield and resistance.

Keywords

Nutrient · Phyto-chemical · Antioxidant · Medicinal value · *Solanum melongena*

P. Hazra (✉)
Department of Vegetable Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India

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10.1 Hunger and Malnutrition

At the beginning of this new millennium, we are still facing an alarming challenge. One billion poor people still suffer from chronic hunger and malnutrition, while about 2.5 billion show under-nutrition and micronutrient deficiencies (FAO 2011). At the same time, about 1.1 billion are overweight and/or obese, a steadily increasing number in all countries in the world (WHO 2011). This double burden is found in both poor developing countries and in Brazil, Russia, India and China. It is noteworthy that an important fraction of the population in industrialized countries is suffering from poverty too and inadequate food and nutrient intakes. The recent trends for these patterns are quite alarming (CDC 2011), thus highlighting the overall inadequacy of food supply and dietary patterns during the last decades and present time worldwide. According to the World Health Report, each year 2.7 million deaths are caused because of a diet poor in vegetables and with stumpy intake of dietary fibre, carbohydrates and proteins (Dias 2013).

Hunger and malnutrition refer to the lack of macronutrients like carbohydrates and protein in the diet. Hidden hunger, unlike the usual forms of hunger like protein energy malnutrition (PEM), is a disorder because of the lack of essential micronutrients in the diet that are absorbed by the body (Uchendu and Atinmo 2010). People suffering from hidden hunger due to lack of vitamins and minerals in the food may appear healthy due to the absence of the classic symptoms of hunger (Uchendu and Atinmo 2010; Burchi et al. 2011). Micronutrients refer to vitamins and minerals essential for the body's physical and mental development, immune system functioning and various metabolic processes (Burchi et al. 2011). Vitamins are organic compounds needed to maintain health and sustain life. Minerals are inorganic micronutrients needed for metabolic reactions (Chavez et al. 2006).

10.2 Nutrients and Phyto-Chemicals

Primary metabolites are proteins, vitamins, lipids and carbohydrates, which are mainly involved in the developmental and physiological developments of plants that are also vital in our diet (Sevindik et al. 2018). A wide range of secondary metabolites along with primary metabolites are produced by plants that influence human nutrition and health as well (Korkmaz et al. 2018). Secondary metabolites are those phyto-chemicals which often play a crucial role against different stresses but are not important for basic metabolic processes of the plant (Sevindik et al. 2017). Moreover, these phyto-chemicals are a vital basis for various medicines and pharmaceutical industry; even recent modern and traditional remedies mainly depend on these phyto-chemicals (Sevindik 2019).

10.3 Tapping the Economic and Nutritional Power of Vegetables

Global value of fruit and vegetable production exceeds that of all food grains combined. Vegetables are mankind's most affordable source of vitamins and minerals needed for good health and are increasingly recognized as essential for food and nutrition security. Vegetable farming provides a promising economic opportunity for income generation among the rural community, reducing rural poverty and unemployment in developing countries, and is a key component of farm diversification strategies. Vegetable is a major component of homestead farming system (HFS); an integration of aquaculture, horticulture and animal husbandry has the potential not only to alleviate poverty, but also to empower women (Srivastava et al. 2013; Schreinemachers et al. 2018).

Vegetables are excellent sources of different primary and secondary metabolites that constitute the main portion of our diet and are considered as a major source of vitamins (A, B complex (B1, B6, B9), and E), dietary fibre, minerals and phytochemicals (Wargovich 2000; Dias and Ryder 2011). Intake of vegetables in our daily diet results in overall good health impact, reduction in gastrointestinal problems and improvement in vision and also plays an important role in reducing danger for various systems of cardiovascular problems, cancer, diabetes, stroke, anaemia, gastric ulcer and other long-lasting disorders (Hyson 2002; Golberg 2003). Lower risk of cardiovascular diseases in humans is strongly associated with high intake of vegetable diet (Mullie and Clarys 2011).

Some phyto-chemicals of vegetables are strong antioxidants and are thought to reduce the risk of chronic disease by protecting against free radical damage by modifying metabolic activation and detoxification of carcinogens or even by influencing processes that alter the course of tumour cells. Study by Bioversity International in collaboration with the FAO revealed that a total of 1097 vegetable species, with a great variety of uses and growth forms, are cultivated worldwide. Of the total of 1097 vegetable species cultivated worldwide, 495 species are used for leaves (leafy green and salad crop); 227 species are used for multiple vegetative parts (bulb, root tuber, stem, leaf, etc.); 204 species are used for roots (root crops); 90 species are used for fruits or seeds; and 80 species are used for other plant parts like flowers, inflorescences and stems. But hardly 80 species (less than 7% of the total species) are more familiar to us (Kays 2011).

10.4 The Crop

Brinjal belonging to the family Solanaceae is a delicate, ligneous, tropical perennial plant often cultivated as a tender or half-hardy annual vegetable crop. The stem is often spiny, which grows 40–150 cm tall, with large, coarsely lobed leaves that are 10–20 cm long and 5–10 cm broad. The fruit is botanically classified as a fleshy berry, with white flesh with a meaty texture and borne singly or in clusters. The fruit contains numerous small, soft seeds that, though edible, taste bitter because they contain nicotinoid alkaloids as found in tobacco. Fruits show a variety of shapes (round, oblong, oval, long and slender, oval-oblong, cylindrical, club shaped) and colours from white, deep green, light green, yellowish, pink and grades of purple pigment to almost black colour and purple with green stripes or streaks and green with violet streaks or blush (Sihachkr et al. 1993; Hazra et al. 2003).

Brinjal or eggplant (*Solanum melongena* L.) is a warm-weather crop and widely cultivated in tropical and subtropical regions of the world. Two other cultivated species, the scarlet eggplant (*S. aethiopicum* L.) and the Gboma eggplant (*S. macrocarpon* L.), are less known but have local importance in sub-Saharan Africa (Schippers 2000; Daunay and Hazra 2012). Global production of brinjal is around 54 million tons annually, with a net value of more than US$15 billion a year, which makes it the fifth most economically important solanaceous crop after potato, tomato, pepper and tobacco (FAO 2018). The top five brinjal-producing countries are China (34.10 million tons; 63.10% of the world's total), India (12.83 million tons; 23.7% of the world's total), Egypt (1.41 million ton; 2.6% of the world's total), Turkey (0.83 million ton; 1.5% of the world's total) and Iran (0.66 million ton; 1.2% of the world's total). It is the fifth most economically important solanaceous crop after potato, tomato, pepper and tobacco (FAO 2018).

According to the Horticulture Statistics at a glance, the Ministry of Agriculture and Farmers' Welfare, Govt. of India (2018), brinjal ranks fourth in the total vegetable production in India after potato, onion and tomato and the top five brinjal-producing states in India are West Bengal (3.027 million tons, mt), Odisha (2.013 mt), Gujarat (1.423 mt), Bihar (1.241 mt) and Madhya Pradesh (1.073 mt).

10.5 Use

Brinjal is a very popular vegetable crop grown for its immature fruits of various shapes, sizes and colours. Culinary preparations of brinjal are quite diverse from curry, sambar, mashed, fried and grilled to stuffed item with spices. *Solanum macrocarpon* is cultivated both for its leaves and immature fruits (Schippers 2000; Maundu et al. 2009). The immature fruits of *Solanum aethiopicum* are used as cooked vegetables in stews and sometimes eaten raw. The leaves and shoots are used as a cooked vegetable.

10.6 Origin and Taxonomy

Although recent information exists on domestication of brinjals, there are still many unanswered questions about this process. Vavilov (1951) considered *S. melongena* as being native to the "Indo-Chinese centre of origin". However, recent evidence suggests that brinjal had a multiple independent domestication from *Solanum insanum*, which is naturally distributed in tropical Asia from Madagascar to the Philippines (Knapp et al. 2013) in several centres of domestication (Meyer et al. 2012). Although the evidence of cultivation of eggplant in both India and China is equally old, archaeological evidence suggests that utilization of wild brinjals may have started earlier in India than China, with a subsequent additional and independent centre of domestication in the Philippines (Meyer et al. 2012). Around the eighth century, brinjal spread eastward to Japan and then westward along the "Silk Road" into Western Asia, Europe and Africa by Arab traders during the fourteenth century, and then it was introduced into America soon after Europeans arrived there (Prohens et al. 2005) and later expanded into other parts of the world. Much less is known on the domestication of the scarlet and Gboma eggplants. Both species were domesticated in Africa, from its respective wild ancestors, which are *S. anguivi* Lam. in the case of *S. aethiopicum* (Lester and Niakan 1986) and *S. dasyphyllum* Schumach. and Thonn. in the case of *S. macrocarpon* (Bukenya and Carasco 1994).

Brinjal belongs to the large Solanaceae family, which contains ~3000 species distributed in some 90 genera (Vorontsova and Knapp 2012). Out of these, *Solanum* L. is the largest one, with around 1500 species (Frodin 2004), and most taxa of this genus have a basic chromosome number of $n = 12$ (Chiarini et al. 2010).

10.7 Nutrient Content of Brinjal

Brinjal has a very low caloric value and is considered among the healthiest vegetables for its high content of protein; various vitamins; minerals like iron, calcium, potassium and magnesium; dietary fibre (Table 10.1); and different bioactive phyto-chemicals which are desirable for body growth (Raigón et al. 2008; Plazas et al. 2014; Docimo et al. 2016). The bioactive properties of brinjal are mostly associated with high content in phenolic compounds (Plazas et al. 2013) having scavenging activities (Whitaker and Stommel 2003), which are mostly phenolic acids, particularly chlorogenic and caffeic acid in the fruit flesh (Bhaskar and Ramesh 2015; Stommel et al. 2015) and anthocyanins (flavonoids) in the fruit skin (Mennella et al. 2012), mainly nasunin and delphinidin-3-(coumaroyl-rutinoside)-5-glucoside (Matsubara et al. 2005; Cassidy et al. 2013). Wide genetic variation was recorded in the total phenol content from 3.26 to 8.77 mg GE equivalent/100 g fresh in brinjal genotypes (Hazra et al. 2003) and from 16.95 to 19.46 mg GE equivalent/100 g fresh in other *Solanum* species, viz. *Solanum aethiopicum* cv.gr. *gilo*, *Solanum anguivi* and *Solanum macrocarpon* (Chattopadhyay et al. 2009). Deep-purple fruited variety, Bidhan Super, had very high anthocyanin content of 103.80 mg/100 g fresh in the fruit skin compared to much low of 12.80 mg/100 g fresh recorded in Bidhan Super, which had light-green fruits with purple streaks (Chattopadhyay et al. 2020).

Both phenolic acids and anthocyanins have multiple beneficial properties for human health (Plazas et al. 2013; Braga et al. 2016). Brinjal is ranked among the top ten vegetables that provide the healthiest food with low calories and also contain high phenolic contents that are helpful in radical-absorbing capacity (Cao et al. 1996; Caguiat and Hautea 2014).

Table 10.1 Nutritional value of brinjal (USDA report 11209)

Nutrient	Content/100 g fresh
Proximates	
Water	92.3 g
Energy	25.0 kcal
Protein	0.98 g
Total lipid (fat)	0.18 g
Carbohydrate	5.88 g
Total dietary fibre	3.00 g
Total sugars	3.53 g
Vitamins	
Vitamin C	2.20 mg
Thiamin	0.039 mg
Riboflavin	0.037 mg
Niacin	0.649 mg
Vitamin B6	0.084 mg
Folate, DFE	22.0 μg
Vitamin A, RAE	1.00 μg
Vitamin A	23.0 IU
Vitamin E	0.30 mg
Minerals	
Calcium	9.00 mg
Iron	0.23 mg
Magnesium	14.0 mg
Phosphorus	24.0 mg
Potassium	229.0 mg
Sodium	2.00 mg
Zinc	0.16 mg
Lipids	
Fatty acids, total saturated	0.034 g
Fatty acids, total monosaturated	0.016 g
Fatty acids, total polysaturated	0.076 g
Cholesterol	0.000 mg

Source: Gürbüz et al. (2018)

10.8 Health Benefits of Brinjal

Brinjal fruit contains various nutrients, vitamins and minerals along with some secondary metabolites having strong antioxidant properties, which play a significant role in keeping good health (Table 10.2). Different research findings show that the fruit extracts have good healing effects on different disorders like burns, warts, inflammatory infections, gastritis, stomatitis and arthritis (Im et al. 2016). The major phenolic compound, chlorogenic acid (5-*O*-caffeoyl-quinic acid; CGA), found in fruit skin (Prohens et al. 2013) works as an anti-obesity, anti-inflammatory

Table 10.2 Health benefits of bioactive compounds of brinjal

Bioactive compounds	Health benefits
Chlorogenic acid, a major phenolic compound in the fruit flesh (Prohens et al. 2013)	• Antioxidant, anti-inflammatory, cardio-protective, anti-obesity and anti-diabetic properties (Plazas et al. 2013; Friedman 2015) • Demonstrates anti-carcinogenic effects by inducing apoptosis in many human cancer cells, such as leukaemia and lung cancer cells (Tajik et al. 2017)
Hydroxycinnamic acids (aromatic acids)	• Antioxidant and free radical scavenging properties, protect from side effects of chemotherapy (El-Seedi et al. 2012)
Tannins	• Enhance glucose uptake and inhibit adipogenesis; inhibit oxidation of LDL cholesterol (Kumari and Jain 2012)
Kaempferol (flavonoid)	• Antioxidant defence against free radicals, reduces the risk of chronic diseases, especially cancer (Chen and Chen 2013)
Quercetin (flavonoid)	• Antioxidant, improves normal cell survival, antiviral, anti-inflammatory, antibacterial and muscle-relaxing properties (Jan et al. 2010)
Luteolin (flavonoid)	• Antioxidant, anti-inflammatory, potentially useful in treating atherosclerosis (Jiang et al. 2013)
Myricetin (polyphenol)	• Antioxidative and cytoprotective effects, anti-carcinogenic actions, antiviral and antimicrobial properties, and anti-platelet activity (Li and Ding 2012)
Nasunin (major anthocyanin in brinjal skin)	• Helps prevent lipid peroxidation and ROS accumulation (Casati et al. 2016) • Helps prevent cardiovascular disease and hyperlipidaemia by reducing low-density lipoprotein (LDL) oxidation; antiangiogenic activities (Matsubara et al. 2005) • Helps prevent inflammation by inhibiting cyclooxygenases (Lin and Li 2017) • Helps prevent obesity by reducing serum triglyceride and cholesterol and increasing high-density lipoprotein (HDL) cholesterol (Seeram et al. 2001)
Delphinidins (anthocyanin)	• Significantly reduce oxidative stress and blood glucose, counteract vascular inflammation (Watson and Schönlau 2015; Braga et al. 2016)
Solasodine (glycoalkaloid)	• Reduces human lung cancer cells in vitro (Shen et al. 2017) • Induces apoptosis in tumour cells (Cham 2007) • Anti-inflammatory property (Ferreira da Costa et al. 2015) • Lower blood cholesterol (Friedman 2006)

(continued)

Table 10.2 (continued)

Bioactive compounds	Health benefits
Lutein (non-provitamin A carotenoid)	• Antioxidant in the retina, protecting the eye from inflammation and oxidative stress (van Lent et al. 2016)
Zeaxanthin (carotenoid)	• Strong antioxidant and pro-oxidant behaviour as well as anti-inflammatory effects, suppresses oxidative stress in the retinal tissue (Manikandan et al. 2016)
β-Cryptoxanthin (carotenoid)	• Precursor of vitamin A • May help prevent free radical damage to biomolecules, prevention and treatment of certain cancers (Lorenzo et al. 2009)
Dietary fibre	• Promotes healthy digestion, thereby reducing the risk of colon and stomach cancer (Fraikue 2016) • High-fibre and low-soluble carbohydrate levels make it a good choice for helping to manage type 2 diabetes (Nwanna et al. 2014) •Reduces hyperglycaemia, hypertension and oxidative stress in those with type 2 diabetes (Nwanna et al. 2016)

and antidiabetic agent and also has cardio-protective functions (Plazas et al. 2013). Chlorogenic acid also shows anti-carcinogenic functions by making apoptosis in many human cancer cells, such as leukaemia and lung cancer cells (Tajik et al. 2017). Afshari et al. (2016) demonstrated that fruit extracts have an extra toxic effect on cancer cells than on normal cells. Fruit extract also has shown an effective action against various bacteria like *Escherichia coli, Staphylococcus aureus, Bacillus subtilis, Bacillus cereus*, *Vibrio cholera* and *Pseudomonas* sp. (Ahmed et al. 2016).

Fruits are a rich source of anthocyanins, which play a significant role against diabetes, neuronal problems, cardiovascular disorders and cancer as well. Purple brinjal has high nasunin content in their fruit skin, which helps against lipid peroxidation and ROS accumulation, which occur due to a high level of iron in cells (Casati et al. 2016). Anthocyanins also raise serum antioxidant volume, support against heart illness and hyperlipidaemia by decreasing low-density lipoprotein (LDL) oxidation (Gürbüz et al. 2018) and play a vital role against gaining overweight by plummeting serum triglyceride and cholesterol, increasing high-density lipoprotein (HDL) cholesterol and decreasing serum triglyceride level (Seeram et al. 2001). Moreover, they are also helpful in ulcer treatment and vision (Ghosh and Konishi 2007; Yousuf et al. 2016).

Carotenoids cannot be synthesized by our body; hence, this antioxidant vitamin should be taken in our diet. Carotenoid-rich food consumption is strongly related to reducing the hazard of some types of cancer (Linnewiel-Hermoni et al. 2015). Vitamin A deficiency is one of the major problems mostly in developing countries, and different carotenoids like lutein, zeaxanthin and β-cryptoxanthin present in brinjal can reduce this problem (Kamga et al. 2013).

Glycoalkaloid compound, solasodine, in brinjal fruit has anti-cancer actions, which decreases human lung cancer cells in vitro (Shen et al. 2017). It also has anti-inflammatory functions and is also beneficial to lower blood cholesterol (Friedman 2006).

Dietary fibre contents of brinjal help in digestion by removing toxins and harmful materials from our stomach, thus reducing the incidence of stomach and colon cancer (Fraikue 2016). Brinjals are a rich source of magnesium, manganese, potassium and copper that are important for healthy bones. Brinjal is also known as Fe-chelator, which is good against anaemia (Cassidy et al. 2013; Bhaskar and Ramesh 2015).

Fruits are important in the treatment of various disorders like asthma, dysentery and high blood pressure and also to cure osteoporosis, arthritis, diabetes, bronchitis, heart diseases and strokes (Sekara et al. 2007; Seneff et al. 2011). Juice extracted from the roots and leaves of brinjal is used to cure skin diseases, cough, anorexia, toothache, burns, general stimulant, piles, inflammation, intestinal foot pain, and throat and stomach difficulties (Sekara et al. 2007). It was recorded that dry brinjal fruits are beneficial in the treatment of stomach bloating, gas and piles, while fresh fruit consumption ensures bone strength, controls diabetes, prevents paralysis and is helpful in teeth-related problems (Cassidy et al. 2013).

10.9 Pharmacological Worth of Brinjal

Crop evolution under domestication provides a fascinating representation of the co-evolutionary processes that continue to shape plant genomes and human cultures. Brinjal originated in the tropical Asia, where fruit and vegetative plant parts have become widely used as both a food and a medicine. No broad surveys were available on ethno-botanical uses of brinjal in different regions of Asia; hence, Meyer et al. (2014) performed an ethnographic survey focusing on three geographically and culturally distinct sites within the Tropical Asia centre of origin: India, China and the Philippines. They conducted household interviews in the three sites to obtain a better understanding on the positive health-related effect of brinjal (Table 10.3).

10.10 Conclusion

Brinjal is an important and popular vegetable crop member of the Solanaceae family with a significant foundation source of various vital nutrient, pharmaceutical and nutraceutical compounds. Although it is an important source of nutraceuticals and pharmaceuticals, few studies have investigated compounds beyond phenolic acids and antioxidant capacity although more than 2500 indigenous cultivars are available in India. Many bioactive compounds of brinjal have not yet been discovered and adequately characterized. Different primary metabolites, like amino acids and carbohydrates, have so far been overlooked. This situation warrants the use of analytical tools and platforms such as metabolomics and metabolic profiling for

Table 10.3 Health-related effect of brinjal on human body system

Human body system	Positive health-related effect of brinjal
Nervous system	Weight loss, heat loss, reduces pain, cure migraine, tranquilizer, good for insomnia treatment, reduces fever
Cardiovascular system	Anti-cholesterol, protects from heart attack, reduces blood pressure, reduces atherosclerosis, stops bleeding, good for enlarged spleen, improves circulation
Gastrointestinal system	Reduces liver problems due to adequate dietary fibre, increases appetite, good for digestion, easy to digest
Urinary system	Reduces blood pressure, diuretic, cleans kidneys
Reproductive system	Good for miscarriage recovery and uterus stabilization, good for foetus development, good nutrition for lactating mothers
Respiratory system	Cures respiratory problems, cures throat problems and cough, reduces phlegm (type of mucus produced in the lungs and lower respiratory tract)
Integumentary system	Reduces freckle and age spot, improves cell elasticity, treats skin rashes and irritation
Metabolism	Weight loss, heat loss, anti-diabetes (American Diabetes Association, USA, recommended brinjal as a component of the diet for individuals with type 2 diabetes (ADA 2015)), good for treating skin and gastrointestinal cancers

Source: Meyer et al. (2014)

the discovery of various bioactive compounds including primary metabolites and characterization of their bioactivity in a less time-consuming and less laborious way. New breeding priorities and strategies need to be framed aiming at improving nutraceutical and pharmaceutical value of brinjal apart from improving yield and resistance.

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11 Home Gardening: The Way Forward to Be Safe and Healthy

M. L. Chadha

Abstract

Home gardens have a distinctive role to play in agriculture, food security, and nutrition. Home gardens enrich local diets by supplementing staple crops with diverse, nutrient-rich vegetable crops; ensure a year-round supply of safe vegetables even when resources are scarce; conserve plant genetic resources and indigenous agricultural knowledge; provide income if adequately linked with markets; and, being located in the vicinity of the homestead, help women harmonize their farming and household tasks, thereby contributing to gender equality in agricultural production. Home gardens may be an entry point to empower the community to manage on-farm agricultural biodiversity while promoting dietary diversity for healthier families and ecosystems. Indigenous vegetables, which are the cheapest source of vitamins and minerals and a high-value food source for the poorest families, can be incorporated in home gardens.

Apart from this, these gardens include home/kitchen. Vertical, container, rooftop, hydroponics, etc. provide for a variety of quality-of-life variables, such as avoidance of stress, recreation, and personal and social identity. Growing fruits and vegetables seems overwhelming to most people, but it is actually much simpler than it sounds. All you need is a few square feet of the great outdoors, a water source, and a little time. Your grandparents did it, and so can you. If you are still not convinced, consider these benefits of home/kitchen gardening which help improve your family's health; save money on groceries; reduce your environmental impact; get outdoor exercise; enjoy better tasting food; build a sense of pride; stop worrying about food safety; and reduce food waste.

M. L. Chadha (✉)
AVRDC—The World Vegetable Centre, Tainan, Taiwan

Madan Chadha Safe Healthy Vegetable Foundation, Hisar, Haryana, India

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Keywords

Home/kitchen · Vertical · Container · Rooftop · Hydroponic · Diet diversity · Indigenous · Nutrient rich · Family health

11.1 Introduction

The novel coronavirus pandemic has affected our lives in almost every aspect imaginable. In fact, experts are predicting that the outbreak of the COVID-19 could have a lasting impact on how we live, work, and eat—beyond the tragedy of lives lost. As the deadly virus worsens its spread, a number of questions may be running through the minds of many: Are those fruits and vegetables at the local market contaminated, or did someone with the coronavirus infection sneeze on those juicy apples?

Experts say that it is not a good idea to use chemicals on fruits and veggies; instead, people should wash the produce as they would with running water. Consuming soaps and detergents can make you sick, leading to gastrointestinal infection with nausea or stomach upset.

Experts suggest that one should rinse fresh produce with running cold water before eating them, which may help remove 90–99% of any contamination. The recommendation also includes washing fruits like banana and foods, which have a peel, before consuming them.

One of the easiest ways of ensuring access to a healthy diet that contains adequate macro- and micronutrients is to produce diverse kinds of foods in the home garden. Home gardens, also popularly known as kitchen gardens, nutrition gardens, or backyard garden, are the areas either adjacent to the houses or slightly further away which are planted with diverse crop plant species of multiple utility and cultural significance providing households with direct access to vegetables and quick-growing fruits that are not readily available or within the families' financial reach. Indigenous vegetables which are the cheapest source of vitamins and minerals, and are high-value food source for poorest families, can be well incorporated in the home gardens. Majority of households engage in some level of gardening or lawn care. Some do it for beautiful flowers, lush grass, and fresh fruits and vegetables. Growing food is another way to make your garden climate friendly, for recycling of biomass, and to get fresher and better tasting homegrown produce. It gives great satisfaction of growing own food/vegetables/fruits. It provides opportunity for physical exercise and aesthetic purposes—peace and quiet or the connection to nature.

In home garden, we usually grow quick-growing fruits like lemon, papaya, guava, and banana; leafy vegetables such as amaranth, Malabar spinach, bathu, chulai, kale, lettuce, sorrel/chuk, spinach, fenugreek, and kangkong; and fruits and flower vegetables like bitter gourd, hot and sweet pepper, luffa, cucumber, eggplant, broccoli, cauliflower, okra, ivy gourd, pumpkin, snake gourd, round melon, tomato, wax gourd, gherkin, zucchini bulb, and tuber and root vegetables: bulbs usually consist of layers or clustered segments such as onion, garlic, and shallot. Tubers grow underground on the root of a plant including sweet potatoes, potato, yam, taro, etc. Roots are a long or round-shaped taproot such as asparagus, kohlrabi, beetroot, carrot, cassava, radish, and turnip. Podded vegetables include all the varieties of beans, peas, and lentils, like black-eyed pea, faba bean, drumstick, Dolichos bean, French bean, pea, lima bean, moth bean, mung bean, rice bean, runner bean, soybean, sword bean, velvet bean, winged bean, and yard-long bean.

Food Safety: To reduce the chance of getting sick from foodborne illnesses, we must wash the fruits and vegetables we grow in our home garden before eating them raw or cooked. Before and after preparing fresh produce, wash your hands for 20 s with warm water and soap. After harvesting, it is time to clean them. Make sure that the area for handling fruits and vegetables is clean, including the kitchen counter and any kitchenware that may be used. Water is the leading option when washing the produce. It is well established that white distilled vinegar, lemon juice, and apple cider vinegar can be slightly more effective than just plain tap water for washing homegrown produce, especially leafy greens in salad and floral greens such as broccoli and cauliflower. To make a vinegar solution at home, mix ½ cup of white distilled vinegar with 2 cups of water. Spray the vegetables with this solution or dip them in it and then re-rinse the produce under clean water. There is a chance that using these alternatives may affect taste and texture. Store most fruits and vegetables in a clean refrigerator at 4 °C or below in a perforated bag to help maintain quality. Make your own perforated bags by making several small holes in a food-grade plastic bag with a sharp object. Remove the outer layers of leafy produce before washing; the outer leaves can conceal bacteria. For produce with thick skin, such as melons, use a vegetable brush when washing. Produce with a lot of nooks and crannies like cauliflower, broccoli, or lettuce should be soaked for 1–2 min in cold clean water.

What are home gardens? An area around the home where different vegetables and fruits are grown throughout the year to meet family nutritional requirements. Or the system of production of diverse crop plant species, which can be adjacent to household or slightly further away and is easily accessible, **or** an intensive type of growing vegetables to minimize buying from the market and to provide continuous supply of fresh nutritious vegetables for the family.

11.2 Characteristics of Home Gardens

Occupy a "small" area in the proximity to the home; cultivation of diverse vegetables for year-round availability; production primarily for household consumption; surplus products sold at the markets in the centers of towns; use of low-cost inputs and indigenous varieties; reducing dependence on exotic or imported varieties; and management by members of household (wife, husband, children).

Home garden technology—for nutrition security Home garden models are based on vegetable crops rich in vitamin A, protein, iron, and iodine, which would supply vegetables for the whole family throughout the year to ensure nutrition security. The broad diversity of horticultural crop species allows year-round production, employment, and income. Intensive horticulture can be practiced on small plots, making efficient use of limited water and land resources, and has a considerable yield potential to provide up to 50 kg of fresh produce per m^2 per year depending upon the technology applied. In addition, due to their short cycle, they provide for quick to emergency needs of food and provide a quick return to meet a family's daily cash requirements. Leafy vegetables are particularly perishable, and postharvest losses can be reduced significantly when production is located close to consumers. No matter if they are urban or peri-urban, all gardens benefit from preplanning and design.

11.3 Types of Gardens

No matter if home gardens are urban or rural, all gardens are benefitted from pre-planning and design. Gardens can be as follows: home/nutritive/kitchen gardens, hanging/vertical gardens, container/terrace gardens, roof gardens, and hydroponics.

11.3.1 Designs of Home Gardens

Cities have limited land; therefore, vegetables have to be grown in a compact area or in the containers.

Between individual families: Some families may have a choice of particular vegetable more than others, whereas other families may have different choices. All these choices determine the designs and types of garden. One may decide to plant more of a particular variety to satisfy their taste regularly, whereas other families may do the other way round.

Family size also makes difference: Large-size family needs bigger garden than small size; hence, design has to be different between the two.

Planning a home garden Best locations for the home/kitchen gardens:

Vegetables grow best where they receive proper light, temperature, water, and nutrients. When any one of these factors is limited, the crop will also be limited in its growth and production. It is important to know the following before you plant:

- Location
- Soil types
- Fencing
- Garden layout
- Types of crops

- Sowing time
- Rotation of crops
- Layout blueprint
- Planting methods and requirement
- Anticipated pests and their control

11.3.1.1 Shape of the Garden Plot

Rectangular and square: This is more convenient to work and more easy to keep clean and neat. It should be open at least on two ends. Practice crop rotation to some extent within the limits of even the small vegetable garden, but it is much better, if possible, to rotate the entire garden patch.

11.3.1.2 Climate: How Where You Live Affects What You Grow

The growing season is, essentially, the length of time an area can give plants the conditions they need to reach maturity and produce a crop. The length of the growing season is totally dependent on the local climate. When you plant a vegetable depends on how well that vegetable handles extremes of temperature. The way a vegetable type reacts to climatic conditions (temperatures, rainfall, sunlight, and day length)—heat, cold, moisture, and so on—determines its "hardiness." The vegetables that are grown in a home garden fall into one of the four hardiness categories: *very hardy, hardy, tender,* and *very tender.*

11.3.1.3 Planning the Home Garden: Cropping Systems and Role of Vegetables

The most suitable way is to plan according to the cropping systems: cool-season and warm-season vegetable planting areas.

- Cool-season vegetables: require cool weather to grow and mature properly and can withstand frost, planted in early spring and again in autumn, including peas, radish, cabbage, onion, carrots, and potatoes.
- Warm-season vegetables: require warm weather to grow properly, planted after the soil has warmed up. Many warm-season crops also need a long growing season and so should be started indoors in early spring or purchased as seedlings ready to be transplanted.

A good option to reduce plant pest problems is to alternate cool- and warm-season areas of the home garden each year.

Different areas around a home have different characteristics: less moist or dry, shady under the trees, lowland, and highland with good sunlight. These areas can be used to grow different types of vegetables, thus ensuring a varied supply of vegetables throughout the year. Fruit vegetables like tomato, brinjal, and okra, requiring full sunlight, can be grown in exposed areas. Climbing vegetables including gourds, drought-resistant vegetables including kangkong and legumes, and shade-loving vegetables like amaranth and other green leafy veggies can be grown close to the house, along the roadsides, and under the shades of other trees.

11.3.1.4 Role of Nutrients from Home Garden

Home gardens can serve as a nutritional garden for family needs. A diversified home garden with diverse species can contribute to the nutritional requirement, particularly leafy vegetables rich in iron, vitamin A, vitamin C, vegetable protein, and dietary fiber. Moreover, food grown at home garden is culturally preferred and valued for safe and fresh for home consumption. Home gardening can be combined with neglected and underutilized traditional crops for providing a variety of food and fruits.

Fruits and vegetable groups actually vary widely in their nutrient contents. Dark, yellow, or orange vegetables or fruits are good sources of vitamin A and iron. Calcium and magnesium are extremely good at absorbing free radicals, and they are essential for strong bones. To achieve this ratio would require eating a very large serving of high-calcium greens with almost every meal. Balanced diets are not accessible for a large proportion of population, particularly those who live in rural areas. Many populations subsist on staple plant-based diets that often lack diversity (and also quality and quantity), which may result in energy deficiencies. Home gardening can improve nutritional status, more specifically micronutrient status of women and children, and reduce poverty, which is one of the appropriate food-based approaches; this could be an essential part of the long-term global strategy to alleviate vitamin A and iron deficiencies, but their real potential still needs to be explored. *Home* gardening could be a good source of healthy fruits and vegetables free from pesticides and fertilizers.

Fruits and vegetables provide many essential nutrients such as vitamins, minerals, fiber, and other substances that are important for good health. The nutrients in fruits and vegetables help to maintain:

- A healthy heart
- A lower risk of certain types of cancers
- Vision and eye health
- A strong immune system and help combat malnutrition in all the forms
- Memory and mental function
- Healthy teeth and gums
- Most fruits and vegetables are naturally low in fat and calories and are filling so they can help to avoid weight gain.

To remain healthy, it is important to consume enough of certain nutrients including the minerals calcium and potassium, the vitamins A and C, and fiber. Use a lot of colorful vegetables to make a salad. Use low-fat salad dressing.

Nutrition-rich vegetable crops for homegardens

Vitamins	Amount	Crops
Vit A	>2000 IU	Amaranth, Malabar spinach, kale, kangkong, lettuce, carrot
Vit B	>17 mg	Legumes, taro, horseradish leaves, banana
Vit C	>20 mg	Amaranth, Malabar spinach, cabbage, kale, kangkong, bitter gourd, lemon, guava, papaya

(continued)

Vitamins	Amount	Crops
Ca	>20 mg	Amaranth, spinach, cabbage, kale, kangkong, lettuce, mustard, beans, onion, turnip, soybean, papaya
Fe	>3 mg	Amaranth, spinach, kangkong, lettuce, chilies
P		Spinach, beans, lettuce, onion, tomatoes, cabbage, broccoli, cauliflower
Iodine		Onion, okra, asparagus

Calcium maintains strong bones and teeth. It helps muscles and blood vessels contract and expand and also helps to send messages through the nervous system. Potassium helps to lower blood pressure, reduce the risk of developing kidney stones, and decrease bone loss. Vitamin C helps heal cuts and wounds, keeps teeth and gums healthy, and also helps to absorb iron. Fiber helps prevent constipation and maintain bowel health. It also helps to maintain a healthy weight as well as lower the risk of diabetes and heart disease. Fruits and vegetables are also good sources of phytochemicals, which are substances in plant foods that are not essential nutrients like vitamins and minerals, but they may have health-promoting properties. They help reduce the risk of heart disease and certain types of cancer. Some are responsible for the flavor, aroma, and color of fruits and vegetables. So, include a rainbow of color in your diet in the form of a variety of fruits and vegetables to get an abundance of phytochemicals.

How many servings of fruits and vegetables are recommended?

1½ to 2 cups of fruits per day and 2 to 2½ cups of vegetables per day. Make half your plate fruits and vegetables.

11.3.1.5 Implementing Home Garden Design

The designed home garden model on 6 × 6 m area each incorporates easy-to-grow, nutritious, and indigenous vegetables. This area could be easily handled by household women, and the produce could be consumed at least by a four-member household. This area can be divided into five longitudinal blocks which are further subdivided into 2–3 smaller subplots measuring 2 × 1, 3 × 1, and 1 × 1 m, respectively, depending upon the crop. Farmyard manure should be mixed in the plot area, and sowing and transplanting of vegetable crops should be done based on crop season and its duration. Fertilizers and management practices should be applied as recommended. The crop selection should be based on the location specificity, cropping seasons, nutritional availability, performance, and family preference. In this model, 27 crops can be fitted into 13 cropping sequences for North India (Fig. 11.1). The model is capable of producing 250–280 kg of fresh vegetables in a year.

Total edible yield Vegetables can be harvested from home gardens twice or thrice every week depending upon their stage of maturity. The average weekly harvest (5.60 kg) provides average daily yields of 200 g per person in a four-member household under North Indian conditions. The 6 × 6 m home garden design for

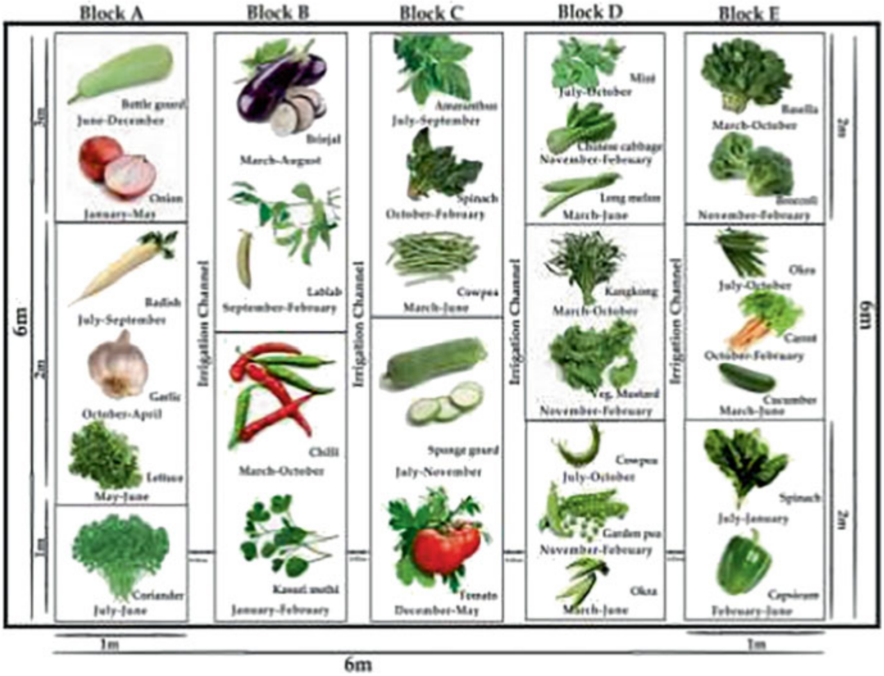

Fig. 11.1 Homegarden blueprint: North India

North India could significantly improve households' access to vegetables and is sufficient to meet the recommended levels in most times of the year.

Design is based on growing safe and healthy vegetables rich in vitamin A, protein, iron, and iodine to ensure year-round supply of vegetables with a yield potential of 250–300 kg/year.

Models can meet >100% of beta-carotene, Vit C requirements, and nearly 3/4th of protein and 1/4th–1/5th of iron requirements.

Nutritional yield The nutrient yield data suggested that while the 6 × 6 m vegetable gardens achieved supplies at recommended vegetable consumption level, vitamin A and vitamin C supplies were sufficient and continued to provide 100–500% of RDA, but protein and iron supplies were difficult to achieve (30% of RDA). High-protein legumes and very-high-iron vegetables should be included in the garden designs to improve protein and iron supplies.

Crop selection for North India module

Plot number	First crop	Follow-up crop 1	Follow-up crop 2
1	Bottle gourd (June–December)	Onion (January–May)	–
2	Radish (July–September)	Garlic (October–April)	Lettuce (May–June)
3	Coriander (July–June)	–	–
4	Eggplant (July–December)	Lablab (September–February)	
5	Chili (March–October)	Kasuri methi (November–February)	–
6	Amaranthus (July–September)	Spinach (October–February)	Cowpea (March–June)
7	Sponge gourd (July–November)	Tomato (December–May)	–
8	Mint (July–October)	Chinese cabbage (November–February)	Long melon (March–June)
9	Kangkong (March–November)	Vegetable mustard (November–February)	–
10	Cowpea (July–October)	Garden pea (November–February)	Okra (March–June)
11	Basella (March–October)	Broccoli (November–February)	–
12	Okra (July–October)	Carrot (October–February)	Cucumber (March–June)
13	Spinach (July–January)	Capsicum (February–June)	–

Get a quality start by selecting varieties which are:

- Reliable and adapted
- Productive with desirable quality
- Resistant to major diseases and insect pests
- Open pollinated or hybrids
- Having good seed procurement
- Having seed that may also be a cutting, rhizome, bulb, or tuber
- Having fresh seeds
- Free from infection, contamination
- With good vigor and germination capacity
- Purchased from a reliable source

Plant spacing and seed

Crop (plot size in m)	Sowing times	Spacing R × P cm	Plant/plot	Seed (g)
French bean (3 × 1)	1	30 × 25	66	50
Onion (3 × 1)	1	15 × 10	217	2
Capsicum (2 × 1)	1	60 × 45	15	0.5

(continued)

Crop (plot size in m)	Sowing times	Spacing R × P cm	Plant/ plot	Seed (g)
Long melon (2 × 1)	1	100 × 100	4	1
Cucumber (2 × 1)	1	100 × 75	6	1
Basella (2 × 1)	1	30 × 15	56	10
Chilli (3 × 1)	1	60 × 45	21	1
Lettuce (2 × 1)	1	15 × 10	126	0.5
Radish (2 × 1; 3 × 1)	2	20 × 10	155	10
Bottle gourd (3 × 1)	1	100 × 100	3	1
Sponge gourd (3 × 1)	1	100 × 100	6	8
Brinjal (3 × 1)	1	60 × 45	18	0.5
Carrot (2 × 1)	1	20 × 10	105	1
Broccoli (2 × 1)	1	30 × 20	36	1
Chinese cabbage (2 × 1)	1	30 × 20	36	1
Garden pea (2 × 1)	1	25 × 15	56	50
Lablab (2 × 1)	1	30 × 15	42	50
Tomato (3 × 1)	1	60 × 45	18	1
Methi (3 × 1)	1	15 × 10	186	10
Amaranthus (3 × 1)	1	15 × 10	217	1
Mint (2 × 1)	1	15 × 15	91	100 cuttings
Garlic (2 × 1)	1	15 × 10	147	
Spinach (2 × 1)	2	15 × 5	366	30
Cowpea (2 × 1)	2	45 × 20	30	30
Okra (2 × 1)	2	33 × 30	21	20
Coriander (1 × 1)	Round the year (4)	30 × 10	55	20
Kangkong (2 × 1)	Round the year (3)	30 × 20	42	16

11.3.1.6 Factors to Consider in Selection of a Garden Site

1. Sunlight
2. Nearness to the house
3. Water
4. Soil
5. Good air drainage
6. Shelter

Sunlight: At least 6 h of direct sunlight each day; 8–10 h is ideal. Garden should be away from the shade of buildings, trees, and shrubs. The best location is a plot sloping a little to the south or east, which catches sunshine early and holds it late. Some leafy vegetables like spinach, mint, and lettuce can tolerate shadier conditions.

Nearness to the house: The closer the home garden to the house, the easier and more frequent to use it. Harvest vegetables at their peaks and thus take maximum advantages of garden for freshness. Weeding, watering, and insect/disease control can be better managed if the garden is close by.

Water: It is essential to locate the garden near a water source. Water as per the need of the crop; avoid over- and under-watering.

Soil: This should be fertile and easy to till—rich, sandy, light, and loam; avoid any soil that remains soggy after a rain. Heavy clay and sandy soils can be improved by adding organic matter.

Good air drainage: Avoid locating the garden in a waterlogged area such as the foot of a slope.

Shelter: Vegetable crops are severely affected in windy sites, reducing yields by 25%. Windbreaks help to baffle and filter the wind.

Shape of the garden plot: square or rectangular: more convenient to work and more easy to keep neat and clean. It should be open at least on two ends.

11.3.1.7 Climate and Home Gardening

- Growing season: Length of time an area can give plants the conditions they need to reach maturity and produce a crop.
- Temperatures: Temperatures, both high and low, affect growth, flowering, pollination, and development of fruits. Ideal temperature: between 4 and 30 °C.
- Rainfall: Too much rain at one time can wash away seeds or young seedlings and damage or even kill mature plants. A constant rain at flowering can reduce pollination of flowers and reduce yields. Too little rain can slow down plant growth and kill young seedlings.
- Day length: Long-day plants need 12 or more hours of sunlight daily in order to initiate flowering. These include radish, onion, and spinach. Short-day plants need less than 12 h of light for flowering. These include soybean. Day length-neutral vegetables do not respond to short or long days, e.g., lima beans.

Different areas around a home have different characteristics—wet near ring wells and tube wells, less moist or dry by roadside, shady under trees, lowland, and highland with good sunlight. These areas can be used to grow different vegetables and would ensure a varied supply of vegetables throughout the year.

- Vegetables like mint can be grown near ring wells and tube wells.
- Fruit vegetables like tomato, brinjal, and okra, requiring full sunlight, can be grown in exposed areas.
- Climbing vegetables including gourds, drought-resistant vegetables, including kangkong and legumes, and shade-loving vegetables like amaranth and other green leafy veggies can be grown close to house, along the roadsides, and under the shade of other trees.

11.3.2 Hanging/Vertical Gardens

Vertical gardening in its simplest form is the idea of vegetables that in their natural state may tend to sprawl over ground and are provided with a support structure for allowing them to grow vertically. A vertical garden is very practical for anyone with a small space to work. Growing vegetables upright also makes harvesting easy.

Vegetables that can do well in a vertical setting include climbing plants like beans and peas. Tomatoes are often staked; indeterminate varieties like cherry tomatoes are often a favorite. Nontraditional choice for vertical gardening is vining plants such as melons, squash, cucumber, and pumpkin. These are a lot like grapes; their vines produce tendrils that wrap around structures and climb as they grow.

11.3.2.1 Support Structure for Vertical Gardens

- Simple stakes or poles: Often used for peas and beans. Simple trellis: A common choice for cucumber. When placing a trellis or stake, be aware of your seasonal wind patterns, and be sure that mature plant is adequately supported.
- Fence: If there is enough sunlight (perhaps a southern exposure), one can use nails to string fishing line or weatherproof twine or other support netting on a wooden fence, or a fence built of chicken wire or some similar structure to provide support.

  Support cage from wood or PVC pipe: Combined with netting to support larger fruits. This is a good choice for some of the cucurbits like melons or pumpkins.

11.3.2.2 Setting Up a Vertical Vegetable Garden

First step is to determine the conditions of the area one wishes to set up vegetable garden, such as in the balcony. The amount of sunlight would be the greatest factor in determining which plants would thrive in the urban environment. If the area is surrounded by other buildings, balcony or patio may be shaded most of the time; one should choose the plants accordingly. Leafy vegetables like lettuce, cabbage, and greens do well with limited sunlight, making a good choice for shady areas. If there is abundance of sunshine, the selection of plants would be more, as vegetables thrive best in full sun. Choices here can include tomatoes, peppers, potato, beans, carrots, and radish. Even vine crops, such as squash, pumpkins, and cucumbers, can be grown as long as the container is deep enough to accommodate them and proper staking is available.

Fill containers with peat moss and a suitable potting mix amended with compost or manure. Steps are as follows:

- Pick the vegetables that we want to grow. There are many that will work with vertical gardens. Beans are great climbers to use. Cornstalks can be positioned against gardening poles.
- Pumpkins can be used at the base for good mulching ground coverage. The pole beans can even climb up the poles that the cornstalks are positioned against or simply up cornstalks. Winter squash can be grown indoors in little peat pots. When these grow, use garden string to tie vines to the trellis.
  - Soft cloth or gardening ropes can be used to prevent any damage to vines.
  - Vining cucumbers can be grown up the trellis using thick garden string to hold vines to the boards. Garden cages are also good for this. Snow peas can be grown up the trellis, garden cage, or netting.
- Use sturdy wire, metal, or wood supports to grow any type of tomato vertically. Use stretchable green tape for securing tomato plants to the structure they are growing up against.
- Water the vertical garden frequently as the plants will be up in the air, and they will dry out quickly. On the other hand, they are less likely to have fungal issues.
  - For any seeds that are sown, make sure that the ground never becomes completely dry.
  - Old plastic grocery bags can also be used.
- Punch tiny holes in the bottom; these retain moisture well, and good results have been found with many different types of vegetables.
- Hanging baskets can be placed on the balcony or on suitable hangers. Numerous types of vegetables can be grown in hanging baskets, especially those with trailing characteristics. Water them daily, since hanging baskets are more prone to drying out, especially during hot spells. Trellises can be used for support of trailing or vine crops. A stepladder can be used as a makeshift trellis to support vine-growing plants like pumpkins, squash, and cucumbers. The rungs of the ladder can be used to train vines while placing vegetables on its steps for further support—this also works well with tomato plants. Growing a vertical vegetable garden is the perfect way for urban gardeners and others to still enjoy a bountiful harvest of freshly grown vegetables.

11.3.2.3 Low-Tech Version Vertical Gardens

Construction debris bags with poked holes for lettuce and other garden veggies to peek out of form a great way to build a garden. This requires a lot less weeding.

Advantages of vertical gardens: Can make use of some otherwise unusable space for the garden. Areas like rooftops or patios can add to the garden with this approach.

A vertically trained plant can be used to improve aesthetics of the yard, hiding things like utility transformers or boxes with a trellis or small fence, or simply dress up a boring wall.

11.3.3 Container/Terrace Gardens

Container gardens are very easy to set up and get started. The only supplies needed are containers, gardening soil, hand rake or tiller, seeds, water, compost (for heavy-feeding plants like squash), and shade nets in hot and arid areas during summer.

11.3.3.1 What to Grow

The most important thing to remember when planting in containers is that the roots of the plants can only go down so far. Make sure that the containers are deep and wide enough to accommodate vegetables. For example, most of the vegetable containers are approximately 12–14 in. wide and 10–12 in. deep. Here is a list of ten vegetables that grow really well in containers: tomatoes, potatoes, cucumbers, carrots, peppers, green onions, turnips, green beans, lettuce, and squash.

While carrots and tomatoes grow well together in the same container, squash needs to be grown in a separate pot; it is a heavy feeder that needs lots of compost, which other plants do not. As its vines grow, it can choke out other plants and keep them from moving past the seedling point.

Main considerations for a container garden are as follows: choosing a proper container, using a good soil mix, variety selection, planting and spacing requirements, fertilizing, watering, and providing 5 h or more of full sun.

11.3.3.2 Choosing a Proper Container

Type of the container depends on the vegetables grown. Containers can be made of clay, wood, plastic, or ceramic. Wooden barrels, decorative boxes, plastic garbage cans, tin cans, plastic laundry baskets, etc. can be used. Small containers dry out quickly and may blow over in the wind. Square, rectangular, or circular containers work equally well.

Dark-colored containers should be avoided because they absorb heat which could possibly damage plant roots. If dark-colored pots are to be used, try painting them in a lighter color or just place the container in shade.

Containers should have adequate number of holes in the bottom for proper drainage. Additional holes are drilled or punched in containers that do not drain quickly after each watering. If the container does not have drainage holes, bottom 1/4 of the container can be filled with rocks or pebbles to hold excess of water until it evaporates or is used. Containers should be raised 2.5–5 in. off the floor by setting on wooden blocks for proper drainage. Plastic materials are nonporous and retain more water; plants grown in these containers dry out less rapidly and can be watered less frequently.

11.3.3.3 Soil Mix/Growing Medium

Growing medium has three main functions—supply roots with nutrients, air, and water; allow for maximum root growth; and physically support plant.

Best to use are commercial potting mixes. These are lightweight, fast draining, and free of insects, diseases, and weeds. Peat-based mixes, containing peat and vermiculite, are excellent. Lightweight mixes though good for hanging baskets, window boxes, and containers that are moved around, are not suitable for growing large plants such as sweet corn, staked tomatoes, and eggplant. The homemade mixes are made from equal amounts of good garden soil, washed coarse sand, and organic material such as peat moss, leaf mold, or sawdust. The mixes need to be free of various pests, and this can be achieved by heating them at a low temperature in the oven. Compost is a dark, crumbly, earthy-smelling product of organic matter decomposition. Leaves, grass clippings, wood waste, and farm animal manures are some of the common ingredients that are combined with water in piles or windrows and digested by huge populations of oxygen-loving microorganisms.

- Some good media mixtures for container vegetables are 100% compost; 100% soilless mix; 25% garden soil + 75% compost; 25% soilless mix + 25% garden soil + 50% compost; 25% garden soil + 75% soilless mix; and 50% soilless mix + 50% compost.
- Recommended media depths are as follows: *10–15 cm*: salad greens, Asian greens, mustards, garlic, radish, basil, cilantro, thyme, mint, and marjoram (salad greens and some herbs have shallow, fibrous root systems and are well suited to shallow containers with a large surface area); *20–30 cm*: beans, beets,

chard, carrots, cabbage, pepper, eggplant, tomato, squash, rosemary, parsley, lavender, and fennel.

11.3.3.4 Vegetables for Containers

A number of varieties have been designed for small gardens and container gardens: These varieties do not grow large but still produce good yields: Most herbs, like parsley, require a standard 15 cm pot; beetroot, lettuce, onions, carrot, and radish require a container holding about one gallon of soil mix; pepper and small tomato varieties grow best with two gallons of soil; large vegetables like cucumbers, eggplants, sweet corn, and tomatoes grow best in four-gallon container or even larger.

- Required pot volume: *1–3 gallons*: herbs, green onions, radishes, onion, chard, pepper, dwarf tomato or cucumber, and basil; *4–5 gallons*: full-size tomatoes, cucumber, eggplant, beans, peas, cabbage, and broccoli.

11.3.4 Window-Box Garden

- Even if someone lives in an apartment, still horticulture can be tried with a window-box garden. Inputs required are window box or hanging box (to hang off your deck), garden soil, seeds, and water. The best type of vegetables to grow in a window-box garden are lettuce, greens, and spinach, as their seeds are sown on the top of the soil, and they do not have deep roots. To grow tomatoes, carrots, and tubers, deeper boxes are either built or bought. Spices such as oregano, basil, and chives also do quite well in this type of garden.
- A scattered garden consists of plots in different areas. Many families do not have a fixed piece of land. Instead, they have various small areas around the home. Use of these small areas to grow different vegetables constitutes a scattered garden. Scattered gardens are more familiar than fixed gardens to landless and marginal population.

  General care: Plants in containers should not be crowded. Thinning should be practiced to allow ample growing space for plants. Root crops and greens should be planted on the basis of the space needed when mature, not as seedlings. Plants should be watered with cool, not hot, water from a hose at moderate pressure. Keep containers together to increase humidity and water retention. If plants are watered in the morning, they will be dry by the evening and help prevent diseases. Containers are watered daily, and so many added plant nutrients are removed from the container. Therefore, they should routinely receive organic materials as fertilizers. Long-season crops like tomato, cucumber, eggplant, and pepper may need to be lightly fertilized every 2 weeks or so to produce a continuous harvest. Tall-growing vegetables should be planted on the north side of the garden so that they will not shade low-growing vegetables.

Planting information for growing vegetables in containers

Crop	No. of days from seeding to germination	Number of weeks to transplanting	General size of container	Amount of light[a] required	Days from seeding to harvest
Beans	5–8	–	Medium	Sun	45–65
Cucumber	5–8	3–4	Large	Sun	50–70
Eggplant	8–12	6–8	Large	Sun	90–120
Lettuce, leaf	6–8	3–4	Medium	Partial shade	45–60
Onions	6–8	6–8	Small	Partial shade	80–100
Parsley	10–12	–	Small	Partial shade	70–90
Pepper	10–14	6–8	Large	Sun	90–120
Radish	4–6	–	Small	Partial shade	20–60
Squash	5–7	3–4	Large	Sun	50–70
Tomato	7–10	5–6	Large	Sun	90–130

[a] All vegetables grow best in full sunlight, but as indicated will also do well in partial shade

Temporary or permanent containers (including window boxes) can be fitted to any location—balcony, deck, stoops, concrete pad, or any part of the yard. Containers can be located where they are most convenient and where they will grow best (place tomatoes in full sun and lettuce in partial shade). Better control over growing conditions (water, sunlight, nutrients) can lead to higher yields with less work than a conventional garden. Container gardens are easier to protect plants from weather extremes, insect pests, and bigger critters. Vertical growth saves space and allows use of exterior walls.

Common problems in container gardening

Effect	Cause	Corrective measures
Plants tall, spindly, and unproductive	Insufficient light	Move container to area receiving more light
	Excess nitrogen	Reduce feeding interval
Plants yellowing from bottom, lack vigor, poor color	Excessive water	Reduce watering intervals; check for good drainage
	Low fertility	Increase fertility level of base solution
Plants wilt although sufficient water present	Poor drainage and aeration	Use mixes containing higher percentage of organic matter; increase the number of holes for drainage
Marginal burning or firing of leaves	High salts	Leach container with tap water at regular intervals
Plants stunted in growth; sickly, purplish color	Low temperature	Relocate container to warmer area
	Low phosphate	Increase phosphate level in base solution

(continued)

Effect	Cause	Corrective measures
Holes in leaves, leaves distorted in shape	Insects	Use recommended insecticides
Plant leaves with spots; dead dried areas, or powdery or rusty areas	Plant diseases	Remove diseased areas when observed and use recommended fungicide

11.3.4.1 Advantages of Container Gardening

It is perfect for all kinds of people—people with physical limitation, college students, renters, gardeners, and any gardener wanting to downsize and save time.

- No digging or tilling is required.
- Container gardening is virtually weed free.
- It is inexpensive to get started. Few tools are needed.
- It helps to overcome some common gardener complaints like backyards that are too shady for tomatoes and compacted, poor-quality soils, and soils contaminated with lead and persistent soilborne disease like *Fusarium* wilt of tomato.

11.3.5 Hydroponics

It is a method of growing plants using mineral nutrient solutions without soil.

11.3.5.1 Setting Up a Hydroponic System

1. **Container for the nutrient solution**: Almost any kind and any shape of the container can be used. The best could be a Styrofoam which holds temperature of the nutrient solution nicely. A container made of wood or bricks lined with plastic can also be used. Plastic sheet for inner lining of the box should be at least 0.15 mm thick to avoid leakage. Depth should be at least 20 cm to provide enough space for oxygen-absorbing roots.
2. **Covering material for the box**: This is generally a netting material with a spacing of about 3 mm × 2.5 mm. It will protect plants from insect damage and also keeps rainwater from entering the nutrient solution. Also, requirement is of some pots or a net bag made from the same net material used for covering and some net for the bottom of the pots.
3. **Nutrient solution**: The solution is made up of many basic chemicals, which provide both macro- and micronutrients. Also needed is some seedling medium like smoked rice hull (the rice hull that has undergone a smoking process). Ordinary rice hull is not effective as a seedling medium. Soil is not recommended either. If smoked rice hull is not available, vermiculite or similar types of seedling media can be used.

Constituents of the nutrient solution[a]

Element	Chemical formula	Concentration (ppm)	Amount (g/L solution)
N	$Ca(NO_3)_2{\cdot}4H_2O$ KNO_3	70.0 30.0	0.59 0.22
P	K_2HPO_4	15.0	0.09
K	KNO_3 K_2HPO_4	38.0 83.8	– –
Ca	$Ca(NO_3)_2{\cdot}4H_2O$ $CaCl_2{\cdot}2H_2O$	100.0 50.0	– 0.18
Mg	$MgSO_4{\cdot}$7H2O	48.6	0.49

[a] Using 4 N H_2SO_4 to adjust pH value to 6.0

11.3.5.2 Setting Up a Hydroponic System

- To begin with, fill the box to about ¾ full of the nutrient solution.
- Prepare the pots for planting. Place a piece of netting on the bottom of the pots. This helps prevent seedling medium from coming down and separating the root system. It also helps in uptake of oxygen and absorption of nutrient solution.
- Net tray rather than pots can be used to plant large-rooted plants such as onion or radish.
- Fill pots about three-fourths with seedling medium.
- Then place the pots into the perforated lid of the box.
- Check that the pots are placed and the solution is 2–3 cm above the bottom of each pot.
- Sow seeds and cover lightly with more smoked rice hull.
- Remember to cover the box with plastic netting to prevent insect invasion.
- When raining, cover the box with plastic to keep out rainwater.
- Leave plants to grow with little care. As the plants grow, roots develop in the box. The roots which are exposed to air are called O roots and roots which are submerged are called WN roots. The success of the hydroponic system is dependent on the rapid growth and quantity of O roots.

Before too long, you can harvest your vegetables; they are healthy and disease, insect, and chemical free.

11.3.5.3 Basic Requirement for a Successful Hydroponic System

1. **Light**—It is essential to carry on photosynthesis. Without this, cultivation of vegetables is not possible, irrespective of the nutrients provided. Sunlight is the ideal source of light required to produce a healthy growth. However, in a hydroponic system, sunlight is not always an option. Artificial horticultural lights can be for a hydroponic gardener; these are cost effective too.
2. **Oxygen-nutrient ratio**: Plants cannot absorb nutrients unless oxygen is present. The higher the oxygen level, the quicker the absorption. Oxygen maintains a healthy root system and allows plants to absorb nutrients. In a hydroponic system,

water is a medium through which nutrients and oxygen are fed to roots. Make sure to keep roots moist, not soaked.
3. **Nutrient strength**: Nutrients must be solely designed for hydroponics. Soil fertilizers utilize bacteria to break down complex elements into useful ones; an ideal hydroponic system has minimal bacteria, if any. Soil fertilizers are less soluble; hydroponic systems require solubility, as the nutrient delivery system is based upon this. Soil fertilizers are generally not pH adjusted, and usually too slow to release necessary elements to be suitable for the system.
4. **Growing media**: In hydroponics, growing media, not soil, hold moisture and anchor roots. Composed of inert mineral matter, it will not decompose or harbor potential soilborne problems. All the plant's nutritional requirements are met with the nutrient mixes.
5. **pH (alkalinity and acidity)**: It is the level of acidity or alkalinity of the nutrient solution. Most nutrients in common tap water will be within the range of 6–6.5 pH, which is suitable for hydroponic system.
6. **Temperature**: In a hydroponic system, temperature requirement is same as out of a hydroponic system.
7. **Air**: Plants require carbon dioxide; it is what they breathe. Poor ventilation would kill plants as surely as a lack of sunlight or water would. Ventilation systems as well as carbon dioxide enrichment and control systems are affordable and available.
8. **Water quality**: In most situations, tap water is just fine for the hydroponic system; over extended periods of time, you may get some mineral buildup, but this is not a major cause of concern. Excessive salinity or high zinc content could be harmful to the hydroponic garden.

11.3.5.4 Advantages of Hydroponic System

Anything can be grown, and there is no backbreaking work, tilling, raking, or hoeing.

No weeds to pull and no poisonous pesticides to spray. No moles or cutworms eat your roots, and most insects leave your clean and healthy plants alone. It is ideal for the hobbyist homeowner or apartment dweller who does not have the time or space for full-time soil gardening. A hydroponic system distributes nutrients evenly to each plant; their roots are not to be pushed through heavy, chunky soil to compete for nutrients. Hydroponic plants grow faster, ripen earlier, and give up to ten times the yield of soil-grown plants. These clean and pampered plants produce fruits and vegetables of great nutritive value and superior flavor.

11.3.5.5 Problems with Hydroponic

1. **How much nutrient to pour over the aggregate?** Assuming that the container is waterproof and that the inside bottom of it cannot be seen through walls or down through the aggregate, it is very difficult to gauge the level of nutrient solution. Without this, it is quite likely that plants would be killed by either under- or overfilling. The only simple solution to this problem is to use a see-through

container, a transparent inspection window, or a float system that will allow a visual check of the nutrient level.

2. **How often to pour nutrient over the aggregate?** The nutrient solution will evaporate from loose aggregates much more quickly than water from soil. Generally speaking, one may have to supply nutrient to plants about once a day. And 1–4 times a day may be necessary depending on light, temperature, humidity, what is being grown, how large are plants, and size of the container. There can be problem of proper aeration of roots. One of the major reasons for using hydroponic aggregate is for aeration.

11.3.6 Urban Gardens

This gardening is the practice of cultivating, processing, and distributing food in or around (peri-urban) a village, town, or city. The key objectives are to make best use of limited land space, limited water availability, as well as recycling of food in the process of sustainable development. Urban gardening contributes to food security and food safety as it increases the amount of food available to people living in cities and allows them to have fresh vegetables.

11.3.7 Rooftop Garden/Rooftop Gardening

Most residential buildings in Indian cities have available roof. But how to build beds that will be watertight enough to keep wet earth from seeping through the roof while still allowing drainage? The rooftop gardening! It should be lightweight and has drainage.

Before we begin, there are a few considerations to take into account—and they are important ones.

Load on the roof: The first step is to evaluate your roof's loading capacity. This is the amount of weight your roof structure can support and includes everything: planter boxes, soil (when wet), possible water storage, weight of crops at maturity, equipment, and such temporary loads as people. This may be your biggest expense and will determine whether you are willing to pursue an edible roof or not. *Always check with your structural engineer on any roof-load issues on rooftop*.

Garden crop selection: Avoid plants with thin stems. Ideal crops for rooftop gardens should be (a) durable and (b) capable of resisting wind and other inclement conditions. (c) Choose low-growing plants like carrots, beets, turnips, lettuce, spinach, and some varieties of climbing beans.

A **roof garden** is a garden on the roof of a building. Besides the decorative benefit, roof plantings may provide food, temperature control, hydrological benefits, architectural enhancement, habitats or corridors for wildlife, and recreational opportunities, and in large scale, it may even have ecological benefits. The practice of cultivating food on the rooftop of buildings is sometimes referred to as **rooftop farming**. Rooftop farming is usually done using green roof, hydroponics, aeroponic or air-dynaponic systems, or container gardens.

A rooftop garden is the ideal alternative way to enjoy all the virtues of gardening and outdoor space when there is no land available. It is ideal for urban environments, where ground space is limited.

- Before we begin, we need to find out if it is possible to create a garden on the roof and the roof is able to hold the weight of a rooftop garden as well as is not damaging the house. Remember to use lighter containers, soil, flooring, furniture, etc.
- Work out a comfortable access way to roof.
- Choose a design, and figure out how you will lay out the roof garden.
- Work out a planting scheme for plants to work well with natural light, humidity, wind, etc.
- Get containers/planters, furniture, etc. to furnish it. All should be lightweight and stable to fix and integrate in the plan/scheme.
- How to water the garden: installing water storage or an automatic irrigation system or by hand depending upon the access to water, etc. Windbreaks should be used as a rooftop garden will be very windy; they should be completely solid, since they will blow over more easily.
- Heat, wind, and heavy rain are the enemies when people want to grow on rooftops. Small platforms will elevate plants slightly above the actual rooftop to increase ventilation around the potted plants.
- Precautions: It is important not to do anything that might damage the property.

11.3.7.1 Home Gardening Is a Great Physical Activity

Gardening can be a great, low-impact exercise. Doctors suggest 30–60 min of low- to moderate-intensity physical activity per day in order to maintain a healthy weight and for heart health. Typical calories burnt (in adults) for 30 min of watering the lawn or garden are 61; mowing the lawn (riding) 101; mowing (push mower with motor) 182; mowing (push mower) 243; trimming shrubs 182; raking 162; planting seedlings 162; planting trees 182; weeding 182; digging, spading, and tilling 202; and hauling heavy rocks 300.

	Energy expenditure (kcal)
Total EP for a 6 x 6 m^2 gardening activities	53786
If we work in the garden:	Energy expenditure (kcal/hour)
One hour per day for 2 months	896
Two hours per day for 2 months	448
One hour per day for 3 months	598
Two hour per day for 3 months	299
If we use the wellness center exercise equipment:	
Treadmill (speed 1.5km/hr)	120
Treadmill (speed 3.0km/hr)	168
Treadmill (speed 6.0km/hr)	270
elliptical trainer (speed 10.7km/hr)	300
recumbent bike (speed 12km/hr)	240

- **Mental, Emotional, and Social Well-Being**
  For many people, home garden is an escape from stress and an ideal place for relaxation. It is the cheapest, healthiest, and keenest pleasure one can get. It gives an opportunity for the family to work together and strengthen ties.

11.3.7.2 Advantages of Having a Home Garden

Advantages

- Produce vegetables free from toxic pesticides
- Cultivation of diverse vegetables for year-round availability
- Production primarily for consumption
- Use of low-cost inputs and indigenous varieties, reducing dependence on exotic or imported varieties
- Management by members of household (wife, husband, children)
  – Vegetables can be harvested at optimum maturity and eaten or preserved while fresh.
  – Fresh vegetables are safe, higher in flavor, of nutritive value, and lower in cost than purchased vegetables, which may also be full of pesticides.
  – Home gardening provides healthful exercise and an interesting outdoor activity for the entire family.
  – It gives a feeling of accomplishment, self-sufficiency, and security.

Andaman's Indigenous and Exotic Vegetables for Nutrition and Entrepreneurship

12

Shrawan Singh and D. R. Singh

Abstract

The indigenous vegetables constitute an important source of dietary micronutrients and livelihood support for poor and marginal communities in rural and tribal regions. Their role has been well accepted in food-based approaches to fight against micronutrient and vitamin deficiencies, which are of main concern for attaining Millennium Development Goals. Although worldwide conservation efforts resulted in huge germplasm conservation at AVRDC-the World Vegetable Centre, Taiwan, and National or Regional Gene Banks, they remain neglected by mainstream research probably due to limited acreage, less commercial demand and overemphasis of few commercial vegetables. These vegetables are vital for survival and health of marginal forest-dwelling communities and remote rural areas, particularly in underdeveloped and developing countries. They have a significant role in generating livelihood opportunities for rural people by engaging them in commercial production, supply chain and seed production and value-added product development and marketing. However, there are certain constraints such as seasonal nature, localized production, poor acceptance in urban population, and limitation in seed and planting material

S. Singh (✉)
Division of Horticulture & Forestry, Central Island Agricultural Research Institute, Port Blair, Andaman and Nicobar Islands, India

Division of Vegetable Science, ICAR-Indian Agricultural Research Institute, New Delhi, India

D. R. Singh
Division of Horticulture & Forestry, Central Island Agricultural Research Institute, Port Blair, Andaman and Nicobar Islands, India

Chander Sekhar Azad University and Technology, Kanpur, Uttar Pradesh, India

Bihar Agricultural University, Sabour, Bihar, India

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availability, which hinders the tapping of potential of these important wild vegetables.

Keywords

Indigenous vegetables · Breeding · Tropical islands · Tribes · Nutrition

12.1 Introduction

Daily intake of healthy vegetables in sufficient quantity (≈300 g: leafy vegetable 125 g, root and tubers 100 g and other vegetables 75 g) is essential for proper nutrition and good health. The global production of fruits amounts to 646.7 million tonnes and vegetables 1159.2 million tonnes (FAOSTAT 2019). This quantum of production appears to be quite sufficient for meeting the requirement, but in real sense, a large segment of human population is still facing shortage of these nutrient-dense foods in various regions and seasons due to one or other reasons. Similarly, India produced 191.77 million tonnes of vegetables from 10.35 million ha area and stands second in the world vegetable production after China (NHB 2019). The per capita gross availability of vegetables in India (388.72 g/capita/day; 2017–2018) has been worked out to be higher than the recommended dietary allowance (RDA), which is only 300 g/day/person (ICMR 2010). The per capita net availability of vegetables (25% loss + 5% exports and processing) was calculated to be 272 g/day (NHB 2018). However, it is hard to accept these theoretical values since a large segment of population still consume less vegetables than prescribed by the ICMR for Indian population (i.e. 300 g/capita/day). It is highly challenging to ensure regular availability of vegetables in remote rural areas, in poor population and in women and children in particular. This can get reference from the National Nutrition Monitoring Bureau (NNMB 2006) report, which brought a serious picture with facts that the daily intake of green leafy vegetables (14 g) and other vegetables (43 g) is grossly inadequate. However, intake of green leafy vegetables was found to be marginally increased to 24 g in a recent survey of the NNMB. This supports the prevalence of micronutrient and vitamin deficiencies and associated diseases in rural population. This is not unique to Indian situation, but Queen's University, Ontario, had a survey in 52 low- and middle-income countries and found that 77.6% of men and 78.4% of women consume less than the minimum recommended servings of fruits and vegetables. Further, consumer behaviour for food is dynamic and regularly evolving, but certain communities have strong attachment with their traditional diets and its vegetable components. In India, various types of vegetables are being cultivated, but only few get predominance in vegetable production. However, the traditional or minor vegetables which are sometimes also called as indigenous vegetables or wild vegetables or underutilized vegetables get very little attention from researchers and development agencies despite their significant contribution to traditional diets and livelihood of people in remote localities. Since these crops are rich in dietary minerals and health beneficial compounds, their significance becomes more in the era of 'Food for All' and 'Nutrition for All'. The indigenous vegetables (IVs) are commercially underexplored, but still they are predominant components in traditional diets of tribal, remote rural or forest-dwelling population. Their rich profile in phytochemicals adds value to counter the risk associated with non-contagious diseases and lower the incidence of micronutrients (Fe, Ca) and vitamins (A, B, C, K). Therefore, they are a robust tool for global fight against anaemia, blindness and other immunity-associated diseases, particularly in most vulnerable and difficult-to-reach population.

The significance of such local vegetables becomes more important when almost 80% of the world's extremely poor people live in rural areas which form a major share (3/4th) of 794.6 million undernourished populations and more than 2 billion people are deficit in micronutrients (WHO 2009). The FAO (2017) report on State of Food Security and Nutrition in the World estimated that 190.7 million (i.e. 14.5%) people were undernourished in India during 2014–2016. Paradoxically, many of them are smallholder farmers. Investigations indicate that reduced consumption of vegetables is linked to poor health and increased risk of non-communicable diseases. Annually, around 6.7 million deaths worldwide are attributed to inadequate intake of fruits and vegetables (Lim et al. 2012). The government schemes in the form of food supply, food fortification and supplementation and biofortification programmes have helped in lifting a significant size of population above the 'line of undernourishment'. Dietary diversity is one of the most effective and sustainable approaches to prevent or minimize the microelement deficiency-related hidden hunger (Thompson and Amoroso 2010). The dietary diversity is associated with better child nutritional outcomes, even when controlling for socio-economic factors (Arimond and Ruel 2004). Thus, these programmes need additional local tools (i.e. nutrient-rich food sources) and activities to substantiate and sustain the ongoing efforts for better outcomes. The indigenous vegetables significantly contribute to food and nutritional needs of the tribes and rural communities (Singh et al. 2011), and many of them are richer than their exotic counterparts. They are abundant, easily accessible, locally adaptable and acceptable in customs and traditions of tribal and settler communities. Hence, the indigenous vegetables have great scope; however, there is need to identify nutrient-rich IVs, breed their nutrient-dense varieties, establish seed/planting material production system, develop commercial production system and marketing network and devise efficient cooking processes and value-added products, sensitizing prospective consumers.

In Andaman and Nicobar Islands (India), the vegetable scenario showed a rising trend where production increased by 134% from 13,200 tonnes in 1991–1992 to 34,623.56 tonnes in 2018–2019 mainly due to increase in area and improvement in productivity (Singh et al. 2012, 2015a). However, the productivity level of vegetables in islands is still very low (7.22 MT/ha) as compared to national average (17.97 tonnes) and the countries having similar kind of climatic conditions to adjoining island countries, viz. Sri Lanka (13.01 MT/ha), Indonesia (≈6 t/ha), Thailand (7.78 MT/ha) and the Philippines (8.70 MT/ha). The indigenous vegetables are more popular in tribes, ethnic communities and rural areas and also occupy a major share in the vegetable market during rainy (60–65%) but very low in dry seasons in the Andamans (10–15%) (Singh et al. 2018). The area and production of any individual vegetable crop are limited due to small size of consumer base, limited production period and absence of export channels.

The islands have heterogeneous population originating from different mainland states in India for food and culture, which appears as a major deciding factor in preference and market potential of vegetables. The indigenous vegetables are easily available and accessible source of various micronutrients and antioxidants. They also add the traditional flavour, colour and taste to food. Few vegetables, namely *broad dhaniya* (*Eryngium foetidum*) and Indian spinach (*Ipomoea aquatica*), have high acceptance among the people regardless of the region, religion, food habits, sex, age, being healthy or patients and socio-economic categories, while many are still having acceptance in specific regions or communities. The research at CIARI showed richness of local vegetables like Indian spinach (*Basella alba*), amaranth (*Amaranthus* spp.), *broad dhaniya* (*Eryngium foetidum*), *daal bhaji* (*Portulaca oleracea*), *madras bhaji* (*Alternanthera* spp.), *khatta bhaji* (*Hibiscus sabdariffa*), *nali bhaji* (*Ipomoea aquatica*) and many others in dietary micronutrients and functional compounds (Singh et al. 2015b, 2018). But their potential needs to be exploited against micronutrient problem in local women and children and also in establishing as a sustainable livelihood option for locals. Here, regional or cluster approach for on-site promotion of local vegetables will be appropriate particularly in tribal or remote villages, which reduces the burden of transportation, storage and even post-harvest losses. Therefore, systematic balanced programmes are required to strengthen the base of native minor crops and also allow the exotic commercial vegetables for benefit of local communities, viz. floating population. This chapter highlights the potential of indigenous vegetables of Andaman Islands and suggests suitable measures for tapping their potential for livelihood generation and entrepreneurship development.

12.1.1 Andaman and Nicobar Islands

The Andaman and Nicobar group of Islands encompass 572 islands situated in the Bay of Bengal, India, with a geographical area of around 8249 sq. km. It stretches between 6°N to 14°N and 92°E to 94°E. The Andaman and the Nicobar Islands are separated by the 10°N Channel (about 90 miles/145 km wide), with the Andaman group lying towards the north while the Nicobar group towards the south (Fig. 12.1). The landmass of islands could be divided into five groups of islands, namely North and Middle Andaman, South Andaman, Car Nicobar, Nancowry and Campbell Bay. It is located at 1255 km from Kolkata, 1200 km from Visakhapatnam and 1190 km from Chennai, the nearest port cities in mainland India. North, Middle and South Andaman, known collectively as Great Andaman, are the main islands, while the others include Landfall Island, Interview Island, Sentinel Islands, Ritchie's Archipelago and Rutland Island. Further, the most prominent islands in Nicobar group of Islands are Car Nicobar in the north; Kamorta, Katchal and Nancowry in the centre of the chain; and Great Nicobar in the South. About 90 miles to the southwest is Great Nicobar situated in the north-western tip of Sumatra, Indonesia. Like other tropical islands, the climate of Andaman and Nicobar Islands is similar to maritime

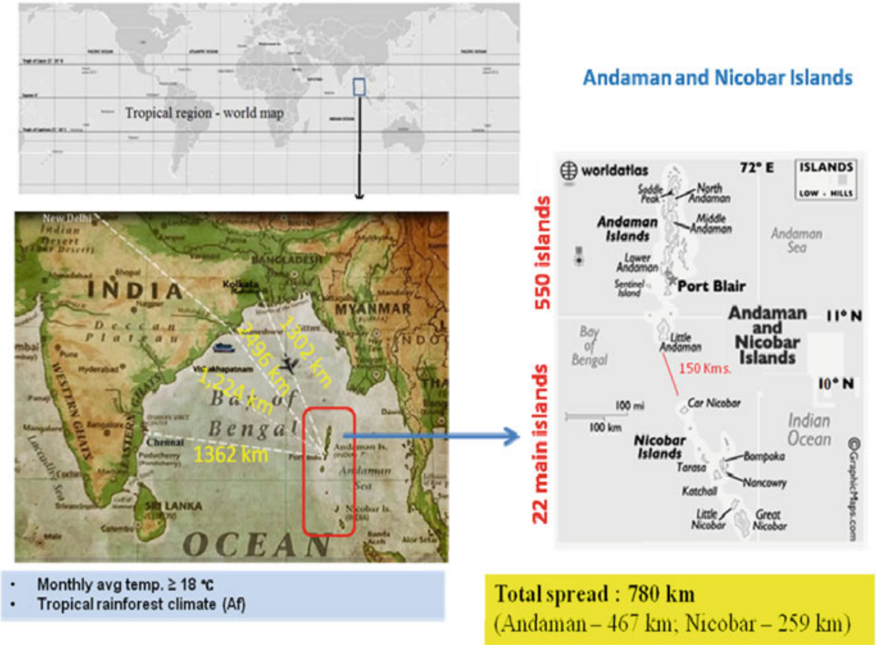

Fig. 12.1 Andaman and Nicobar Islands: geographical location

climate. There are two distinct cropping seasons in ANI based on the rainfall pattern, viz. rainy season (May–December) and dry season (January–April). Rainy season is characterized by plentiful rains (400–600 mm/month) and average temperature ranging from 23 to 27 °C with predominant cloud cover (Fig. 12.2). The relative humidity also remains much higher (80% or above) during rainy season. Dry season is rain-free period (except some incidental heavy rains during February–March months) with comparatively lower average temperature (21–24 °C) during early and main period of this season (December–February months), while the later phase of dry season faces higher temperature (28–33 °C). The relative humidity remains low (65–75%) during dry season. Thus, dry season is relatively cool and rain free, with less humidity and soil moisture and abundant sunlight, while rainy season is characterized by heavy rains, high humidity and soil moisture, and poor sunlight due to cloudiness. Commercial vegetables occupy a major share, while in rainy season, indigenous leafy vegetables have significant presence in the local markets.

The archipelago house six indigenous tribes including the Nicobarese, the Jarawa, the Shompen, the Onges, the Sentinels and the Great Andamanese with distinct dialects and languages (Basic Statistics 2011) and have their traditional food system. Besides, a major share of the island population consists of the settler communities, which arrived in islands during the nineteenth century because of British imprisonment, followed by penal settlement. The Islands represent 'mini India', because the population comprises people from various traditions, food cultures, religions, languages and regions. People have varied food habits because

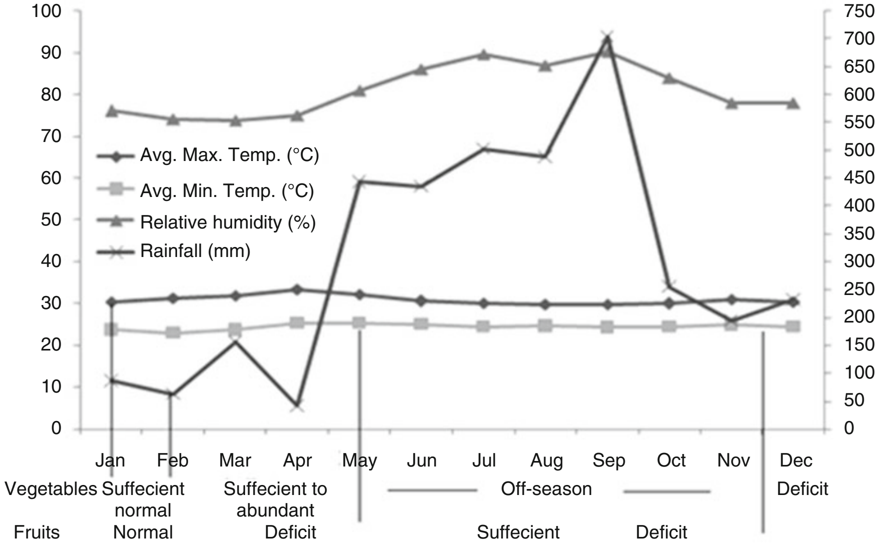

Fig. 12.2 Climatic profile of Andaman and Nicobar Islands and vegetable production scenario. (Source; Singh et al. 2015a)

of heterogeneous culture of indigenous tribes and settler communities. Some islands have emerged as commercial production centres for different agri-horticultural crops, which act as a supply source for non-farming population primarily due to differences in food and cultural preferences, technological interventions and market opportunities (Singh et al. 2018).

12.1.2 Land Distribution Pattern in Andamans

Lowland soils are clayey and silty in nature, while upland soils are predominantly gravely clay loam, weak, sub-angular blocky, friable and slightly sticky with moderately rapid permeability. The C/N ratio ranges from 16 to 21 (Pandey et al. 2007). Forests have maximum share (86.2%) in islands followed by revenue lands (about 7%) and agriculture (6%) (Basic Statistics 2011). Total area under cultivation in the islands is 43,552.1 ha of which maximum is in North and Middle Andaman (18,057.5 ha) followed by Nicobar district (13,900 ha) and South Andaman (11,595.2 ha). Major share of crop land lies in North, Middle and South Andaman Islands, while very little area is under cultivation in Nicobar group of islands. In cultivated land, coconut (20,070 ha), rice (5701.12 ha), areca nut (44,335.8 ha), fruits (3583.35 ha) and root crops (426.41 ha) are the major crops. Vegetable crops are being cultivated on 4795.46 ha area, mostly as post-paddy crop in dry season or in uplands during rainy season. Therefore, there is a great challenge to meet the food demand of 3.79 lakh local people from only 50,000 ha of cultivated lands. Further, a major share of vegetable production comes from North and Middle

Andaman (18,336.68 MT) followed by South Andaman (15,732.25 MT) and Nicobar districts (554.88 MT). There is a great inter-island variation in the islands, i.e. South Andaman (10.09 MT/ha), North and Middle Andaman (6.52 MT/ha) and Nicobar Island (1.30 MT/ha). Since 'organic agriculture' relying on minimal use of agro-pesticides is advocated owing to sensitive terrestrial and marine biodiversity in the islands, it further heightens the challenges of achieving high productivity. However, vegetables are well responsive to organic sources of essential nutrients. Further, the soils in upland situation of islands are acidic and organic sources of nutrients improve the soil health and increase the buffering capacity of soils. Prevalent cropping patterns in the islands are identified as paddy-vegetables/pulses/maize, paddy-fallow, fallow-vegetables and paddy-vegetables-vegetables (North and Middle Andaman); paddy-vegetables-fallow, vegetable-vegetables-fallow, fallow-vegetables and paddy-pulses/maize (South Andaman); and rice-vegetables and vegetables-vegetables (Nicobar Islands) (Table 12.1).

12.1.3 Constraints in Growing Commercial Vegetables

Geographical stretch of the islands from 6° N to 14° N latitude is attached by climatic variability from Northern to Southern islands. Along with climatic and input supply factors, reach of technological interventions also has disparities across the islands, which describes inter-island variations in cropping pattern as well as productivity. High humidity and warm temperature in these tropical islands cause several disease and insect pest constraints. The unstructured surveys revealed major biotic constraints in the vegetables as leaf curl in chilli and tomato; bacterial wilt in solanaceous vegetables; borers in okra, legumes, brinjal and tomatoes; and diamondback moth in cole crops. Heavy rains and low light during rainy season and drought and intense sunlight during dry season are constraints in attaining quality and potential yield of vegetables. The crop-specific constraints are given in Table 12.2. Interaction with farmers of different islands during 2008–2011 period in different training programmes highlighted that heavy rains and diseases are major constraints in the cultivation of high-value vegetables.

12.2 Defining Indigenous Vegetables

Indigenous (traditional) vegetables are best defined as species that are locally important for the sustainability of economies, human nutrition and health, and social systems (NDASH) but which have yet to attain global recognition to the same extent as major vegetable commodities such as tomato or cabbage (Keatinge et al. 2015). The defining criteria of indigenous vegetable crops (IVs) are the following:

– Plants consisting of culinary herbs, shrubs, trees, vines and indigenous or introduced acclimatization to local conditions
– Indispensable part of traditional food culture
– No agro-techniques to realize their potential

Table 12.1 Major vegetable crops grown in A&N Islands and comparison of productivity with national average for the year 2013–2014

Crops	Andaman and Nicobar Islands			India			Productivity (island vs. mainland) (%)
	Area (000 ha)	Production (000 MT)	Productivity (MT)	Area (000 ha)	Production (000 MT)	Productivity (MT)	
Bitter gourd	0.4	1.7	4.3	78.9	807.5	10.2	140.85
Bottle gourd	0.2	1.1	4.8	103.2	1818.9	17.6	270.96
Brinjal	0.6	3.3	5.8	711.3	13,557.8	19.1	230.23
Cabbage	0.1	1.3	15.6	400.1	9039.2	22.6	44.58
Cauliflower	0.5	4.6	9.4	1073.7	433.9	0.4	−95.70
Cucumber	0.3	1.6	5.4	43.3	678.1	15.7	192.00
Chillies	0.2	0.4	1.9	140.0	1687.3	12.0	529.81
Muskmelon	0.0	0.3	15.5	36.7	760.8	20.7	33.76
Okra	0.8	4.6	5.4	532.7	6346.4	11.9	119.00
Radish	0.3	1.5	5.4	173.3	2484.8	14.3	164.08
Sitaphal	0.3	2.0	6.7	19.8	416.1	21.1	212.74
Sweet potato	0.2	2.7	15.8	105.9	1087.9	10.3	−35.06
Tapioca	0.2	4.3	17.7	228.3	8139.4	35.7	101.35
Tomato	0.1	0.7	5.4	882.0	18,735.9	21.2	294.49
Watermelon	0.1	1.7	20.6	74.6	1809.8	24.2	17.56
Others	2.5	20.1	8.0	1574.4	19,108.2	12.1	52.55
Total	6.9	51.8	7.5	9396.1	162,896.9	17.3	130.64

Source: NHB Database 2014

Table 12.2 Ranking of constraints and promising technologies in vegetable production in the islands

Vegetable crop	Major biotic constraints	Major abiotic constraints
Tomato	Bacterial wilt, leaf curl, late blight	Heavy rains, poor transportation facility, poor fruit set, blossom end rot
Capsicum	Bacterial wilt, mites, leafy curl	Heavy rains, sunscald, fruit borer, mis-shaped fruits
Brinjal	Bacterial wilt, fruit and shoot borer	Heavy rains, waterlogging, poor fruit setting
Okra	Yellow vein mosaic, fruit borer, fruit rot, jassids	–
Chilli	Bacterial wilt, leaf curl, anthracnose, thrips	Heavy rains, high temperature
Cauliflower/ cabbage	Diamondback moth, Spodoptera, curd soft rot	Heavy rains, high temperature, buttoning and loose curd, head cracking in cabbage
French bean	Mosaic virus, pod borer	Heavy rains, heat and humidity, acidic soils
Cowpea	Mosaic virus, pod borer	Heavy rains, fruit rot
Dolichos bean	Mosaic virus, aphids, pod borer	Heavy rains, poor pod setting, heat stress
Palak	Leaf spot and holes in leaves	Heavy rains, poor quality of leaves due to high heat in March–April, incidental flooding
Kohlrabi	Diamondback moth, Spodoptera	Heavy rains, poor tuber quality, cracking
Cucurbits	Foliar diseases	Heavy rains, low fruit setting, bitterness
Muskmelon	Downy mildew, powdery mildew	Heavy rains, fruit cracking
Fenugreek, coriander	Leaf minor, aphids	Bitter taste in open condition, heavy rains
Local leafy vegetables	Leaf minor, leaf spot	–

- No seed production or marketing systems
- No breeding attempts to improve genetically
- Grow in wild, home gardens or small-scale farms
- These criteria are close to the terms 'indigenous leafy vegetables' (Jansen van Rensburg et al. 2007), 'traditional food crops' (FAO 1997) and 'indigenous traditional vegetables' (Keatinge et al. 2011).

The IVs are common food for vulnerable communities and constituents in traditional diets for taste and food value and serve the millions of poor people across the globe. In Andamans, IVs are vital for tribal and local people. These are easily accessible and readily acceptable cheapest food in geographically challenged regions and in contingent situation. The IVs provide an option for livelihood and entrepreneurship to tribal and rural youth. They have natural tolerance to biotic and abiotic stresses and are hence good candidates for climate-resilient agriculture and also organic farming. They grow in different growing situations with minimal efforts and inputs and are hence a good option for fragile ecosystem. Improved varieties can contribute significantly to improving the nutrient status of island population. The potential of indigenous vegetables with special emphasis on Andaman and Nicobar Islands is discussed hereunder:

12.3 Diversity of Indigenous Vegetables in Andamans

Region-specific survey was conducted during 2008–2013 across three districts covering the islands, namely Campbell Bay, Kamorta, Car Nicobar, Little Andaman, South Andaman, Neil Island, Havelock Island, Middle Andaman and North Andaman. Around 150 cultivated/wild species of vegetables have been reported to occur in the island by Singh et al. (2016). Maximum share is contributed by less used indigenous leafy vegetables (ILVs) (18.0%) followed by perennial vegetables (17.3%). The common leafy vegetables contribute to about 6.7% of total vegetable diversity, while commercial vegetables have 16.0% share. The island is a rich centre of diversity for (1) leafy vegetables, i.e. *Centella asiatica*, *Enhydra fluctuans*, *Amaranths* sp., *Ipomoea aquatica*, *Momordica dioica*, *Hibiscus sabdariffa*, *Alternanthera philoxeroides*, *Colocasia esculenta, Portulaca oleracea*, *Sauropus androgynus*, *Capsicum annum* and *Solanum melongena* (Singh et al. 2016); (2) lesser known leguminous vegetable crops like tree bean (*Parkia roxburghii*), sword bean (*Canavalia gladiata*), faba bean (*Vicia faba*), velvet bean (*Mucuna pruriens*) and *Mucuna* (*Mucuna gigantea*); (3) cucurbitaceous vegetable crops, i.e. *Momordica*, *Luffa*, *Trichosanthes* and *Coccinia*; (4) local chilli and brinjal; and (5) perennial vegetable crops (Fig. 12.3). We made efforts and conserved germplasm of indigenous vegetables in crops such as amaranth (48), chilli (60), cowpea (10), drumstick (10), *Eryngium foetidum* (10), Indian or Ceylon spinach (*Basella alba* and *B. rubra*) (10), *Momordica* spp. (5), *Ipomoea aquatica* (5), *Alternanthera* spp. (4), *Enhydra fluctuans* (4), *Sauropus androgynus* (2) and others (40).

12.4 Potential Uses of Indigenous Vegetables in Nutrition and Entrepreneurship in Islands

12.4.1 Indigenous Vegetables Can Reduce Drain of Island Economy

The gross state domestic product (GSDP) of Andaman and Nicobar Islands is 8846 crores with per capita net state domestic product of Rs. 199,842 in 2020 (Basic Statistics 2020). The contribution of the tertiary sector (69.94%) was maximum followed by the secondary sector (17.25%), while the primary sector contributed only 12.81% to the GSDP in 2020. A significant share of income returns back to mainland India as charge of goods and services including vegetable crops. This ‘drain of economy’ can be reduced at least by producing vegetables locally to meet

Fig. 12.3 Diversity of indigenous vegetables in Andaman and Nicobar Islands

the demands of local population and tourists, particularly in rainy season when the islands have off season for commercial vegetable crops. The tourist flow to Andaman Islands shows an increasing trend, and to tap the full potential of the sector (Chand et al. 2015), it is essential to boost the local production centres for meeting their fresh food requirements, particularly vegetables. For this, breeding of biotic and abiotic stress-tolerant varieties adaptable to heavy rains in open condition and tolerant to partial shade and humid conditions inside the protected structures is a prerequisite. In Andamans, the indigenous vegetables have potential and taste to substitute the commercial vegetable crops, i.e. *Hibiscus sabdariffa* for sourness in place of tomato; *Eryngium foetidum* in place of leafy coriander; local tuber crops in place of potato; exotic chilli by local chilli materials for pungency; local legume vegetables to replace the import of exotic legumes; multiplier onion for common onion; indigenous pickle items; and *Limnophila chinensis* for composite flavours, which is also desirable to minimize the import of vegetable crops.

12.4.2 Indigenous Vegetables Are Fitting to Nutritional Security Schemes

The tropical regions will house around 55% of the world's population by 2050, but these are more vulnerable to climate change impacts (https://tropicaldatahub.org). Resource shrinkage due to rise in human population and climatic vagaries in these regions invite attention for measures to ensure food and nutritional security. In this context, the indigenous foods including vegetables could serve a better and easy source for dietary microelements (Baruah and Borah 2009) because they have showed a vital role in the fight against micronutrient deficiencies in vulnerable communities due to their easy accessibility and better acceptance in traditional diets (FAO 1988). Indigenous vegetables of islands rich in important dietary minerals and phytochemicals are given in Table 12.3. Anti-nutritional factors in indigenous vegetables limit the bioavailability of dietary micronutrients. Hence, efficient cooking processes are necessary to minimize the effects of unfavourable elements while retaining the benefiting ascorbic acid, anthocyanin and carotenoids (Udousoro et al. 2013; Singh et al. 2015b). Lack of systematic information of nutritive profiles, inconsistency and inadequacy in the supply of nutrient-rich vegetables and lack of efficient cooking practices hinder the integration of vegetables in nutritional security schemes. In natural habitats, indiscriminate exploitation has led to a situation of 'more efforts less harvest', while poor market and technological support are major constraints in commercial farming of these vegetables. Proper rationing of harvest through community participation is essential to retain the regenerative capacity of the natural habitats and ensure sustainability of traditional food system. This could be reverted by breeding of nutrient-rich varieties in prioritized indigenous vegetables and developing suitable production technologies (Singh et al. 2015c).

Table 12.3 Dietary nutrients from indigenous vegetables for vulnerable population

Constituents	Rich indigenous vegetables (mg/100 g dw)
Ca (mg/100 g dw)	*Murraya koenigii* (830), *Centella asiatica* (583), *Hibiscus sabdariffa* (450.5), *A. viridis* (416), *Eryngium foetidum* (350)
Mn (mg/100 g dw)	*Centella asiatica* (54.5), *Ipomoea aquatica* (33.1), *Colocasia esculenta* (32.8), *Alternanthera philoxeroides* (31.4), *Portulaca oleracea* (29.5)
Zn (mg/100 g dw)	*Centella asiatica* (45.3), *Colocasia esculenta* (41.7), *Enhydra fluctuans* (24.0), *Amaranthus viridis* (23.9), *A. philoxeroides* (16.4)
Fe (mg/100 g dw)	*H. sabdariffa* (187), *C. asiatica* (179), *A. lividus* (124), *E. foetidum* (106)
Mg (mg/100 g dw)	*Amaranthus viridis* (738.1), *A. philoxeroides* (586.5), *Centella asiatica* (579), *Enhydra fluctuans* (463.4), *Portulaca oleracea* (332.7)
Polyphenol (mg/100 g)	*Sauropus androgynus* (1151), *Coccinia grandis* (487.3), *Basella alba* (311), *Corchorus capsularis* (307.5), *Moringa oleifera* leaves (295.9)
Chlorophyll (mg/100 g)	*Colocasia esculenta* (267), *Corchorus capsularis* (264), *Alt. philoxeroides* (262.8), *Dryopteris filix-mas* (259.9), *Nymphaea stellata* (251.7)
Ascorbic acid (mg/100 g)	*Cucurbita moschata* leaves (314.2), *Centella asiatica* (308.8), *Alt. philoxeroides* (297)
Tannin (mg/100 g)	*Hibiscus sabdariffa* (519.4), *Portulaca oleracea* (510.3), *Piper sarmentosum* (508.4), *Amaranthus tricolor* (476.3), *Eryngium foetidum* (473.3)
Flavonoids (mg/100 g)	*Alternanthera philoxeroides* (614.4), *Jussiaea repens* (595.6), *Basella alba* (546.7), *Cucurbita moschata* (541.1), *Enhydra fluctuans* (450)
Anthocyanin (mg/100 g)	*Amaranthus tricolor* (288.7), *Ipomoea aquatica* (241.4), *Basella rubra* (230.0)

12.4.3 Indigenous Vegetables Are for Immediate Use to Mitigate Climate Change

The productivity of vegetables remains low in tropical islands (Olasantan 2007), which could be due to genotypic and environmental factors or their interactions. Bray et al. (2000) reported yield losses of around 50% in vegetable crops primarily due to environmental stresses. In future, the climate-associated stress events like high temperature, limited soil moisture and salinity stress will get magnified by climate change impacts (de la Peña and Hughes 2007). Frequency of extreme events is likely to affect the response of technologies including high-yielding genotypes against soil health degradation or changes in disease and pest equilibriums and reproductive biology with modified microclimate. The Andaman and Nicobar Islands are geographically isolated from continental India and form an archipelago of 572 islands fragmented by seawater. The islands have high vulnerability to the extreme impact of natural disasters like tsunami and cyclonic storms (Krishnan et al. 2011). Although a systematic review was made by de la Peña and Hughes (2007) for improving vegetable productivity in a variable and changing climate with specific attention to tropical continental regions, there is little progress in exploiting the real potential of these crops to harness their strength in climate change mitigation strategies. Singh and Bainsla (2014) also presented an analysis of available options for breeding of climate-resilient traits in vegetable crops with main emphasis on indigenous vegetables for the Andaman and Nicobar Islands.

12.4.4 Indigenous Vegetables Are Suitable Option to Utilize Degraded Land and Water Resources

The *Tsunami* (26th December 2004) damaged around 8068.71 ha of precious agricultural lands (out of total 50,000 ha of agricultural land) of the Andaman and Nicobar Islands and directly affected the livelihood of more than 6000 farmers. It caused total losses to island agriculture to the tune of INR 321 crores. It caused losses to plantation crops by 28% in Katchal Island, 17% in Car Nicobar (home of Nicobarese tribes) and 13% in Campbell Bay (also commercial plantation of settlers). Small islands like Teressa (744.0 ha), Kamorta (637.0 ha) and Trinket (329.0 ha) Islands were mostly washed out by seawater. These lands were submerged by seawater which created saline soils, and lowland areas got flooded during rainy season. Although the raised-bed technique is quite effective, the challenge is to breed varieties which can tolerate high-salinity stress. Local germplasms of wild *Ipomoea* sp., *Alternanthera*, *Portulaca* and *Amaranthus* sp. were seen in the *Tsunami* (2004)-affected lands, indicating their potential to identify varieties suitable for salt-stress situations. Further, occasional submergence of lowland areas warrants for root zone during rainy season. In such situations, *Ipomoea aquatica* and *Alternanthera* were most prominent across the waterlogging areas. On the other hand, water is an important limiting factor for vegetable cultivation during the later phase of dry season, i.e. March–April months, which necessitates breeding of drought-tolerant varieties to attain economic yield of quality produce in the islands.

12.4.5 Indigenous Vegetables Can Develop Local Seed Sector

The development of local seed sector in islands is important for reducing the cost factor, generating local livelihood through seed/planting materials and restricting the entry of unwanted weeds and insect pests along with seeds/planting material. The approximate estimation indicates that around 22,000 kg of vegetable seeds are required every year in the islands. Local production of vegetable seeds is almost negligible except a few local types by the farmers/tribals; therefore, almost the entire demand of improved seeds/planting materials in vegetable crops is being met through imports from mainland by private sector or government agencies. This makes the seed a very costly input and risks the island ecosystem. Hence, quality seed production of important vegetable varieties is of utmost importance to curb seed cost and ultimately cost of cultivation. This can be done by (1) identifying/developing local varieties in important commercial vegetable crops, (2) releasing the improved varieties in indigenous vegetable crops, (3) testing and releasing established varieties/hybrids of commercial vegetables from mainland-based public institutes for the island region, (4) providing adequate training of selected farmers for seed production and providing them necessary input and buy-back support and (5) developing local seed production, storage and distribution in the line of 'seed village' concept through participatory mode. It is quite evident that private seed industries and government seed agencies are exploring new areas for seed production; for this, these islands can serve the purpose particularly in open condition during dry season and protected condition during rainy season. This is because climatic conditions during January–April remain suitable for cultivation and seed production of all cucurbits, okra, legume vegetables, solanaceous vegetables and leafy vegetables. The vegetable seeds are of quite low volume but of high value, and hence their transport in inter-island and to mainland is quite feasible. The economic benefits of seed production, geographical isolation, climatic suitability and high level of literate unemployed youth could be favourable for the growth of seed sector in the islands. This is particular for indigenous vegetables, which are specific to the islands; breeding varieties locally and seed production system are essential to provide adequate seed quantities to the growers at right time and in affordable cost.

12.4.6 Indigenous Vegetables Are Best Option for 'Organic Andaman' Mission

The organic farming is very much necessary to sustain the coastal life and ecosystem in the islands. This is because heavy rains and washing-off of chemical pesticides from crop field to water bodies are serious challenges to water bodies and coastal life (Swarnam and Velmurugan 2013). Local administration is promoting organic farming of vegetables in phased manners in the islands by giving financial support and inputs for integrated nutrient management (INM) and integrated pest management (IPM). The indigenous vegetables are important components for successful organic farming since (1) they are well versed with disease and insect tolerance (escape or genetic resistance); (2) they have low demand of external nutrient inputs; (3) they are weedy in nature and have rapid ground coverage, so weed problem is less which ultimately avoids the use of chemical weedicides; (4) the vegetables are fitting well in the small-scale production modules such as home gardens, kitchen gardens, school gardens and community gardens, which are predominantly by default organic; and (5) in Andaman, the coconut and areca nut plantations are being developed as organic gardens in 'Organic Andaman' mission and the indigenous vegetables grow well as intercrop in these plantations, therefore fitting well in crop models for organic farming. Therefore, these crops are among the best candidate crops for organic farming, and small interventions in these crops have the potential to substantially diversify the 'Organic Andaman' basket for localities and export markets. The production and pre-market activities for indigenous crops are commonly done by local women and labourers, which increases their job opportunities and ultimately livelihood. To support the local efforts for cost-effective management of insect pests in vegetable crops, Birah et al. (2010) showed the inhibitory effect of aqueous leaf extract of cloves (*Syzygium aromaticum*) on the growth and development of tobacco caterpillar (*Spodoptera litura*). The group also reported the effectiveness of different eco-friendly management modules against fruit fly in cucurbits. Singh et al. (2014) reported the usefulness of growing prepared by use of locally available materials such as coconut husk, farmyard manure or vermicompost and lime for management of bacterial wilt in tomato. Also, use of locally available rootstock, i.e. *Solanum torvum* and *Solanum melongena* genotype CARI Brinjal-1, was very effective to manage bacterial wilt. However, such efforts need to be explored for other crop diseases and pests.

12.4.7 Indigenous Vegetables Best Candidates for Enriching Home Gardens and Community Gardens

Settlements in tropical islands have home gardens as an integral component of their house plan and to meet their Udousoro day-to-day requirements of fruits, vegetables and medicinal plants partly or fully. Vegetables are an important constituent of these tropical home gardens (Pandey et al. 2007) dominated by bottle gourd, sponge gourd, leafy vegetables, chilli, brinjal, okra, cowpea and some local vegetables. During the survey of home gardens in the islands, we found that the Indian spinach (or poi), broad dhaniya, amaranth, chilli and drumstick were most common. Drumstick, jackfruit and bread fruits are also common in boundaries, while low-growing herbs such as *Centella asiatica*, *Eryngium foetidum* L. and *Bacopa monnieri* are grown in earthen pots. Tsunami (2004) damaged the traditional home gardens of the indigenous tribes, but new home gardens having better crops and varieties were established to meet up the daily needs of horticulture-based food items. Intensity of home gardens in rural areas of islands is higher (65%) as compared to peri-urban (40%) areas, where manpower is oriented towards commercial farming. The efforts were directed towards modernizing the home gardens with more crops and improved varieties, scientific production technologies, rain shelters, soil mount technique and use of multi-storey cropping system, assuring irrigation water for dry phase and providing improved farm implements. But more research efforts are suggested to find suitable varieties and devise modules for maximum edible product from components of home garden to meet up the maximum share of household needs for food items. Further, scientific evidence of increase in the nutritional status of household members by adoption of home gardens is needed to promote this concept.

12.4.8 Indigenous Vegetable-Based Processing, Value-Added Food Items and Bioprospecting

Value addition is important for forest/farm produce collected at small scale by locals or small farmers since they hardly find market/s due to unorganized structure, small quantities and short shelf life of harvested fruits and vegetables. For this, there can be a three-tier strategy, wherein tier 1 can focus on immediate products with minimal resources and technology-based value-added bulky products for direct consumption

Fig. 12.4 Indigenous vegetable (broad dhaniya)-based fortified food items: dried leaf powder, idli, vada and biscuits

of local consumers and regional market, tier 2 for moderate level of intervention for technologies and resources for regional/national markets and tier 3 for large low-volume high-value products for national and international market by developing a complete chain of production to consumers. The tier 1 and 2 activities from such wild plants will increase price and transform traditional practices to profitable businesses and give reason for large-scale cultivation of traditional vegetables. The common processed products from such crops are drying items, fermented products, dry powder, canning, flakes, pickle, cookies, juices, etc. (Singh et al. 2018). Most of the indigenous vegetables are suitable for processing in tier 1, and few strong candidates for tier 2 strategy are broad dhaniya (*Eryngium foetidum*), medak bhaji (*Centella asiatica*), dal bhaji (*Portulaca oleracea*), drumstick (*Moringa oleifera*) and aam bhaji (*Limnophila chinensis*). In islands, the sun-drying of amaranth, roselle, curry leaf, pumpkin leaf, *aam bhaji*, broad dhania, drumstick leaves, teasel gourd and gac was noticed. Local fortified items, namely *murukku*, *vada, idli and biscuits*, from *broad dhaniya*, Centella, red amaranth, pumpkin flower and green amaranth were also told by the locals (Fig. 12.4). Dried leaf powder as taste enhancer from aam bhaji, Roselle, curry leaf and dal bhaji could be a potential item. The tier 3 activities are very important for regional economy since it involves export sector and better price of the product; therefore, there are certain targeted crops like aril fraction of teasel gourd (*Momordica subangulata* var. *renigera*) and gac or sweet gourd (*M. cochinchinensis*) for lycopene (Kubola and Siriamornpun 2011; Singh et al. 2015; Singh et al. 2017a); leaves of red amaranth and ripe fruit extracts of *Basella alba* and *B. rubra* for anthocyanins (Singh et al. 2019); calyx of *Hibiscus sabdariffa* (Singh et al. 2013); pods, flowers and leaves of *Moringa oleifera* (Singh et al. 2017b); functional compounds from *Trichosanthes tricuspidata* (Dubey 2013); and *Mucuna pruriens* for Parkinson's disease (Lees et al. 2004). Usually, these wild vegetable/fruit products are rich in bioactive compounds; hence, they have the potential to be exploited for the development of functional foods for national and international markets. Transfer of appropriate technologies and establishment of mutually agreed contract farming system between local producers are a prerequisite to improve the product quality and production of innovative food products and thus empower people to contribute to food business.

12.4.9 Indigenous Vegetables Can Serve as a Tool for Empowering Rural Women

Horticulture and value addition are indeed the best approaches for small-scale farmers in rural areas to change their economic status. Value addition increases product demand allowing producers to benefit from increased profits due to increased sales. Women are key players in farming in small landholdings, home gardens and collection of products from natural growing areas like forest/farmlands. The involvement of women is more particularly in vegetable production in rural areas and doing the light-to-moderate drudgery activities in the home gardens and community gardens. They are also directly involved in marketing in the local daily or weekly markets and preparing value-added products for household use or market. The IVs play a key role in women empowerment through different activities as simplified in the given line diagram (Fig. 12.5). The promotion of indigenous vegetables through participatory research and development activities has shown good impact on livelihood empowerment of women in African region (Ayanwale and Amusan 2014; Taremwa et al. 2016). Gupta et al. (2019) also highlighted the significance of women empowerment and market integration in improving the status of nutrition of rural population in India. Sensitizing women for efficient cooking practices of underutilized vegetables also contributes to improving the nutrition of family members, which ultimately reduces the risk of diseases, thereby saving medical expenses. Cooking practices improve the useful antioxidants by softening of the tissues and increased extractability of compounds (Miglio et al. 2008), and also boiling vegetables with normal or 5% salt water reduces the anti-nutritional factors significantly (Singh et al. 2015). However, establishing self-help groups (SHGs) and Farmer Producer Organizations (FPOs), imparting modern skills through customized training activities and providing necessary technology, machineries and market linkages through government or NGOs are essential to attain the desired outcomes.

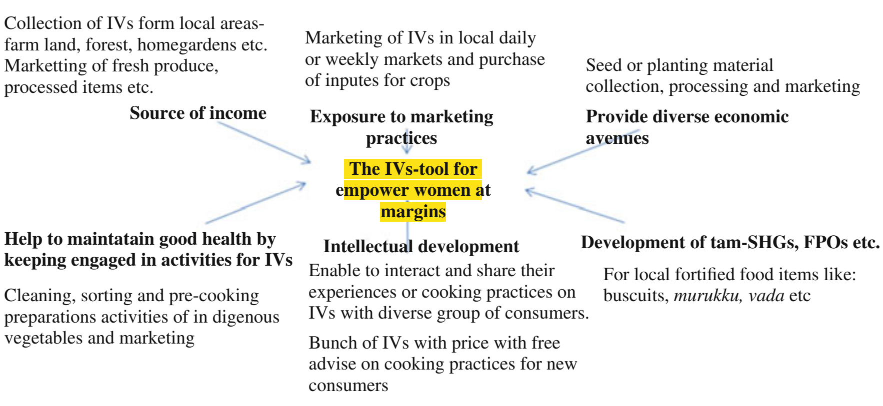

Fig. 12.5 Indigenous vegetables in women empowerment in the Island region

12.5 Technological Options for Island Vegetable Sector

Vegetable sector contributes significantly to the livelihood of local people and island economy, but majority of these crops have very low productivity even than the national average. Over the years, the CIARI (earlier CARI) has made lot of efforts to find suitable varieties, standardize island-specific production technologies, conduct field training/extension activities and supply seed/planting materials to farmers. Local administration also contributed immensely to uplifting the sector through the supply of quality seeds and other inputs and conducting extension programmes for local farmers. The most appropriate technologies for the island region are briefly described hereunder:

12.5.1 Suitable Varieties of Vegetables for Increasing Vegetable Productivity in Island Condition

Analysis of secondary data from reports of different experiments on vegetables such as All India Coordinated Research Project (Vegetable Crops), field observations on vegetable experiments or farmers' fields showed that dry season is most favourable for open cultivation of vegetable crops. Selection of right variety/hybrid is very important for higher yield and to minimize the impact of local climatic constraints. In this direction, suitable varieties identified in different exotic vegetable crops during 2008–2014 are given in Table 12.4. It also contains the list of improved genotypes of indigenous vegetables. Around 25–30% of total vegetable coverage (6400 ha) is under these recommended vegetables. Maximum area of cauliflower and capsicum (>90%); significant area of French bean, palak and radish (>60%) and major portion of okra, chilli, tomato and bitter gourd area are covered by these recommended varieties. The varieties were also identified in 13 different vegetable crops for protected cultivation in the island conditions. The varieties identified in cucurbits for the islands are given in Table 12.5. The identified varieties in cauliflower, palak, sweet pepper, French bean, chilli and coriander have played a substantial role in the promotion of protected cultivation in the islands.

12.5.2 Improved Genotypes of Indigenous Vegetables

The islands have diverse indigenous vegetable crops, and it becomes difficult to perform breeding on such a large number of crops; therefore, the crops were prioritized based on a mean score (0–100 scale) derived from a score matrix of ten parameters, namely (1) prevalence in local markets (high/medium/low/absent), (2) quantity sold in market (approx.kg/day), (3) consumer preference (high/medium/low/no), (4) intensity in home gardens/consumer gardens (high/medium/low/absent), (5) farmers/growers' needs, (6) available diversity in local germplasm (abundant/good/fair/few), (7) frequency of consumption (days/month), (8) quantity of household consumption (kg/month), (9) food and nutritional value (strong/

Table 12.4 Identified vegetable varieties for open and protected cultivation in tropical island conditions

	Open condition		Protected condition	
Crops	Most promising genotypes/ varieties	Crop season	Variety	Crop season
Tomato	Ayush (24.0 t/ha), Arka Rakshak (24.t/ha), Arka Vikash (22 t/ha), Laxmi (18 t/ ha)	Dry season	Ayush (38.0 t/ha), Arka Vikas (25 t/ha), Arka Rakshak (25 t/ha), G-600 (24.0 t/ha)	Year round
Brinjal	CARI-Brinjal-1 (25.8 t/ha), BB-54 (23.73 t/ha), VNR 218 (19.37 t/ha), KS 331(18.23 t/ha), Punjab Sadabahar (17.14 t/ha)	Year round	CARI-Brinjal-1 (15.0 t/ ha), Pusa Purple Cluster (14.0 t/ha)	Rainy season
Chilli	LCA-353 (10.2 t/ha), Arka Lohit (9.7 t/ha), KA-2 (8.5 t/ ha), CIARI-Chilli-1 (23.3 t/ha)	Dry season	KA-2 (15.0 t/ha), Arka Lohit (12.0 t/ha)	Rainy season
Sweet pepper	None of the tested varieties found suitable	Dry season	Indra (45.0 t/ha), California Wonder (35.0 t/ ha), Arka Gaurav (32 t/ha)	Year round
French bean	Arka Anoop (10.2 t/ha), Swarna Lata (9.1 t/ha), Arka Komal (7.4 t/ha)	Dry season	Arka Komal (12.0 t/ha), Arka Anoop (8.0 t/ha), Pole-type advance lines from IIHR	Rainy season
Cowpea	Arka Sumangala (9.5 t/ha), Swarna, Harita (9.5 t/ha), Green Fall (8.5 t/ha), Arka Garima (11.0 t/ha), Kashi Kanchan (9.0 t/ha)	Year round	–	–
Dolichos bean	IIVR Sem-8 (9.65 t/ha), IIVR Sem-11 (9.28 t/ha), IIVR-Sem-186 (7.13 t/ha), Gomuchi Green (6.46 t/ha)	Dry season	Arka Jay (10.0 t/ha), Arka Vijay (7.2 t/ha)	Rainy season
Cauliflower	White Marble (24.2 t/ha), White Shot (17.4 t/ha)	Dry season	White Marble (24.5 t/ha), White Shot (18.5 t/ha)	Year round
Broccoli	Palam Samridhi (5.9 t/ha), Pusa KTS-1 (5.4 t/ha)	Dry season	Palam Samridhi (5.5 t/ha), Pusa KTS-1 (5.2/ha)	Rainy season
Radish	Pusa Chetki (32.6 q/ha), Pusa Himani (22.2q/ha), Japanese White (15.7q/ha)	Dry season	Pusa Chetki (26.0 t/ha)	Rainy season
Okra	Sakti (14.0 t/ha), Arka Anamika (12.0 t/ha), HOKE 152 (11.5 t/ha)	Year round	–	–
Bitter gourd	Priya (10.91 t/ha), Coimbatore Long (9.04 t/ha), Arka Harit (5.6q/ha)	Dry season	–	Year round
Ridge gourd	IAHS-1 (7.08 t/ha), Jaipur Long (5.42 t/ha)	Dry season	–	–
Coriander	CO-1, Mehak	Dry season	CO-1 (7 t/ha), Mehak (5 t/ ha)	Year round

(continued)

Table 12.4 (continued)

	Open condition		Protected condition	
Crops	Most promising genotypes/ varieties	Crop season	Variety	Crop season
Palak	All Green (11.0 t/ha), Palang Banarsi (7.9 t/ha), Pusa Bharti (14.5 t/ha)	Dry season	All Green (22.0 t/ha), Pusa Bharati (18.0 t/ha)	Year round
Mustard sag	Pusa Sag-1 (18.6 t/ha)	Dry season	Pusa Sag-1 (20.0 t/ha)	Year round
Amaranth	CARI-Harita (15 t/ha)), CIARI-Lal Marsha (14 t/ha), Arka Suguna (12.5 t/ha, Pusa Kiran (9.5 t/ha)	Year round	CARI Harita (17.5 t/ha), CARI Lal Marsha (16.0 t/ ha)	Year round
Poi (Basella)	CARI Poi Selection (18–21 t/ ha), CIARI Shan (16–18 t/ha)	Year round	CARI Poi Selection (24.0 t/ha), CIARI Shan (22.0 t/ha)	Year round
Broad dhaniya	CARI Broad Dhaniya (8.0 t/ ha)	Dry season	CARI Broad Dhaniya (9.0 t/ha)	Year round

medium/poor/no) and (10) prioritized crops for genetic improvement like *Eryngium foetidum*, *Basella alba*, *Amaranthus*, *Hibiscus sabdariffa*, *Ipomoea aquatica*, *Portulaca oleracea, Alternanthera* spp., *Centella asiatica* and *Moringa oleifera*.

In indigenous leafy vegetable crops, breeding programme was started in 2008 in the island, which resulted in the development of one variety of *Eryngium foetidum* L. (CARI Broad Dhaniya), two varieties in *Basella alba* L. (CARI Poi Selection) and *Basella rubra* L. (CIARI-Shan) and two varieties of *Amaranthus viridis* L. (CIARI-Harita) and *A. tricolor* (CIARI-Lal Marsha) for tropical island conditions (Fig. 12.6a). The detailed characteristics of these varieties are presented in Table 12.5. Further, elite genotypes from local germplasm were developed in prioritized indigenous vegetables such as *Momordica subangulata* subsp. *renigera* (CARI Kakrol-1; uniform attractive green fruits with high yield potential (80–90 q/ ha) in island condition), *Hibiscus sabdariffa* L. [CIARI HS-1; attractive green leaves, uniform growth, high yield (130 q/ha), early (35–40 days) and tolerance to foliar diseases], *Centella asiatica* (L.) Urban (CIARI CA-5; broad leaves, rich in micronutrients and yield 30–35 q/ha), *Ipomoea aquatica* L. (CIARI NB-4; attractive green leaves and green stem, fast-growing habit and with yield potential of 80–90 q/ ha), *Portulaca oleracea* (CIARI DB-8; rich in polyphenol, Ca, Fe and for problem soils), *Alternanthera* spp. (CIARI MD-2; purple green leaves and high yield 11–14 t/ ha; CIARI MD-1: green leaves, tolerant to heavy rains and waterlogged situation and high yield) (Fig. 12.6b) and *Capsicum annum* L. (CIARI-Chilli-1, 2, 3, 4 and 5); all are identified as resistant to bacterial wilt and leaf curl with yield potential between 90 and 130 q/ha (CIARI 2013; Singh and Bainsla 2015).

Table 12.5 Improved varieties in indigenous vegetable crops developed at CIARI, Port Blair

Crop	Variety	Chief character
Broad dhaniya	CARI Broad Dhaniya	It is the first variety of this crop in India and developed through mass selection using local germplasm from Andaman Islands. It produces 30–35% higher yield than base material. Its leaves are rich in micronutrients and phytochemicals. The variety fits well in 'zero land cultivation' concept. The average yield is around 8–10 t/ha/year
Indian spinach (green)	CARI Poi Selection	It is a new and first variety of Indian spinach (green type). It has attractive green and broad leaves, short internodal length and better shelf life. It is rich in Fe and Ca, ascorbic acid and carotenoids. It is highly suitable to tropical climatic condition of islands and yields around 18 t/ha (with single harvest) and 54–60 t/ha with multi-harvest, which is 42–57% higher than local base materials. It was released by the IVRC of ICAR-CIARI, Port Blair, in the year 2013
Indian spinach (red)	CIARI-Shan	It is a first variety of *Basella rubra* L. and is developed using local germplasm through mass selection method. It has dark attractive purple/magenta colour stems and green leaves with coloured veins and short internodal length. It is rich in anthocyanin (leaf—280 mg/100 g; stem—410 mg/100 g FW) and micronutrients (Fe, 8.4 mg/100 g; Ca, 202.8 mg/100 g DW). It is ready to harvest at 35–40-day stage when it attains a height of 25–30 cm. It has yield potential of 48–52 t/ha with multi-harvest and 15–18 t/ha in single harvest. It grows well in partial shade (50%) with organic inputs
Amaranth	CIARI-Harita	It has attractive green and broad leaves, fast growth habit, high preference among the farmers and consumers and high biomass yield. It is rich in antioxidants like chlorophyll (707.8 ± 7.3 mg/100 g) and carotenoids (509.5 ± 2.5 mg/100 g). It is well suited to tropical climatic conditions of Andaman and Nicobar Islands and has a fast-growing habit. It has green leaf yield potential of 13–15 t/ha in island conditions
Amaranth	CIARI Lal Marsha	It is a promising selection for higher yield, attractive leaf colour and better adaptability to tropical warm humid climate of islands. It has attractive broad and purple/magenta leaves, fast growth habit and high acceptance by farmers and consumers. It is preferred in home gardens for its attractive colour, which also adds ornamental value. It is rich in anthocyanin (288.7 ± 1.8 mg/100 g), a strong antioxidant for better health. It has green leaf yield potential of 14–16 t/ha in the tropical islands
Brinjal	CARI Brinjal-1	It has high level of resistance to bacterial wilt. It bears light green oblong-shaped fruits. Plants have medium height, semi-spreading type with profuse branching habit
Sweet potato	CIARI-SP-1	The individual tuber weight is 81 g and yields 20.87 t/ha
	CIARI-SP-2	The CIARI-SP 2 is another addition, which has twining spreading plant with intermediate growth rate and intermediate internode length. It has medium-sized mature green leaves and purplish-green colour leaves when immature. The individual tuber weight is 93 g and yield 22 t/ha

12.5.3 Protected Cultivation Technology for Vegetable Crops

Like mainland India, the indeterminate tomato, capsicum and parthenocarpic cucumber are preferred choices for protected cultivation in the islands. This is mainly due to floating population (tourists, service-class people) and urban population. However, in rural and remote islands, only tomato had preference and other crops like cauliflower, palak, French beans, radish and determinate tomatoes are in preference list. This is mainly due to low incidence of soil-borne diseases, high market prices in rainy season, simple and less cost involved in cultivation and assured high price market. In comparison to rainy season, the yield of vegetable crops remains very high in dry season, which ranges from 80.0% (Indian spinach) to 833.3% in knol khol (Table 12.3). Large differences were also observed in the yield of bottle gourd (575.8%), cauliflower (450.0%), radish roots (400.0%) and cucumber (369.2%). Heavy rains create dampness in soil, severely affect germination and plant stand, damage floral parts, affect pollination-fertilization activities and hamper the development of edible parts. In cauliflower, curd soft rot remains a major problem in rainy season. The protected cultivation technology has proved to be a great success in various parts of the world and in different climatic regimes. This is one of the most intensive farming systems, which have on an average 5–10 times more crop productivity than open cultivation. This technology has great potential in islands to improve the productivity and also make the island self-sufficient in vegetable production particularly during rainy season and also meet the quality

Fig. 12.6 (**a**) New varieties of indigenous vegetables from Andaman and Nicobar Islands. (**b**) Improved genotypes of indigenous vegetables from Andaman and Nicobar Islands

Fig. 12.6 (continued)

standards of hotels and defence forces. It ensures quality of produce and also protects crops from biotic and abiotic stresses like heavy rains, diseases and pests. Due to 'island effect', there are three issues which need adequate attention for effectively exploring the potential of this technology. First, in conventional polyhouses, the inside temperature remains very high at 35–45 °C during most part of the year, which is not fit for most of the high-value vegetable crops. Second, supply of frame materials from mainland and its inter-island transport remain big challenges due to limited logistic facilities, and third high-speed winds and local wind storms damage the structure more frequently. Thereby, structures need to be customized for local climatic condition and considering the locally available resources. Locally customized low-cost protected structures include rain shelters for growing vegetables in rainy season, net houses for insect-free brinjal and cauliflower in dry season and shade nets for cauliflower, high-value leafy vegetables and French beans in later period of dry months (March–April) when temperature becomes very high for these crops (Fig. 12.7). Further, the low-cost structures with local inputs are effective to attract the attention of local youth/farmers both in tribal and rural areas. They feel attached with them right from construction to growing crops inside these structures. Further, such structures fit well within the available space in home gardens, which increases their productivity and utility. Suitable varieties were identified in different vegetable crops for protected cultivation in the island condition. In capsicum, Singh et al. (2020) reported 'Indra' (63.6 t/ha) and 'California Wonder' (48.3 t/ha) as the high-yielding varieties for protected cultivation in the islands; however, the incidence of bacterial wilt in natural field ranged from 26.0% (Arka Gaurav) to 39.3% (Bomby).

Fig. 12.7 Growing cauliflower in three different structures: (a) shade net during March–April (late dry season), net house during November–January (early dry season) and rain shelter during August–November (rainy period)

12.5.4 Production of Seedlings and Planting Materials

Timely availability of healthy seedlings of vegetable crops is a big challenge for farmers. This is of particular significance for dry-season crops such as cauliflower,

Fig. 12.8 Raising nursery in low tunnels, polytunnels and polyhouses in Andaman Islands

cabbage, tomato, chilli and brinjal because the nursery production activities for these crops start when rainy season gets over in November–December months. Alternatively, raising nursery in protected structures in the months of October–November can help in advancing the crop almost 1 month than conventional practices. Untimely heavy rains during nursery stage also damage seedlings heavily. Therefore, nursery protection structures like rain shelters, polytunnels or polyhouses are better options (Fig. 12.8). The raised beds (2–3 m length; 45 cm to 1 m wide and 15–30 cm) are prepared by applying well-decomposed FYM/cow dung manure @ 1.5–2 kg/sq m. The beds are finely prepared, and seeds treated with bavistin @ 2 g/kg are sown 1.5–2 cm deep and 5–7 cm apart lines. Normal irrigation and intercultural operations are performed timely. The sheet of polytunnels or rain shelter is unrolled during sunny hours while covered during heavy rains. The seedlings are ready between 30 days (tomato) and 40 days (cauliflower, cabbage, chilli and brinjal). This is a very affordable livelihood option for small-scale beginners since it requires very nominal inputs. Further, the polytunnel and polyhouse are suitable for medium- to large-scale production of vegetable seedlings. This technology has great commercial prospect in island conditions in particular.

Further, the islands have a serious problem of bacterial wilt in solanaceous vegetables, particularly tomato, brinjal, chilli and sweet pepper. Large number of varieties/hybrids in tomato, sweet pepper and brinjal (from mainland India) were tested, but due to high inoculum load and congenial climate, the incidence of disease remained very high (Singh et al. 2014, 2019). CIARI Brinjal-1 (IC0585684; IGNR12015), an improved green fruiting genotype developed from the local ecotype of *Solanum melongena*, was found to be resistant to bacterial wilt in island condition (Krishna et al. 2012). Grafting technique was found most successful for bacterial wilt management for tomato cultivation in open and polyhouse cultivation (Singh et al. 2014). Although robotic machines are available for high-throughput grafting in vegetable crops, limited demand and technical know-how favour more towards locally adaptable options such as manual grafting. In this line, the island rural and tribal youth have great opportunity to produce grafted plants in nurseries and market to needy farmers. Interestingly, the islands are a reservoir of the rootstock

Fig. 12.9 Grafted tomatoes in pots and harvested fruits in polyhouse in Andamans

berry brinjal (*Solanum torvum*), which grows in natural habitats. The grafting of tomatoes on *S. torvum* is shown in Fig. 12.9.

12.5.5 Land Manipulation Technologies for Vegetable Production

The techniques in land management were developed to utilize the problem soils as well as increase the yield and factor productivity (in terms of yield and efficiency) in island conditions. For this, three technological modules were developed for vegetables:

1. Raised bed technology for vegetable production in lowlands: This technique is suitable for all vegetable crops in low and medium lands. In this, raised beds of 20–30 cm height and 45–80 cm width are made and two rows of planting are found suitable (Fig. 12.10a). It saves water (20–25%) and labour (30–40%) and increases marketable yield (10–20%). The technology is adopted in Neil, Diglipur, Rangat and South Andaman. This technique allows the crop plant to grow healthy and face minimum waterlogging stress as plants are grown on ridges and furrows act as drainage lines for excess water. This method also reduces weed infestation, saves water and increases the quality of fruits and yield. The plant damage by excess water was also significantly reduced by this system over the flat-land system in palak, brinjal, chilli, poi and broad dhaniya. Further, making raised bed with locally available coconut stems on sides of the bed (Fig. 12.10b) is very effective to reduce soil erosion from the beds during rainy season in particular.
2. Trench system with local growing media: This technology is useful for growing vegetables on hard or rocky soils, problem soils, soils in coastal areas or seawater-inundated lands (during Tsunami 2004). In islands, there are two major concerns: (1) shifting of soil is prohibited due to ecological requirements and (2) soils in uplands are crusty/hard or rocky, which are unfit for economic cultivation of vegetables, particularly by adopting protected structures. Further, low soil pH invites soil-borne problems in solanaceous vegetables like bacterial wilt. For such soils, trench system was found very effective. In this, trenches of 30–45 cm width and 20–30 cm depth are made and filled with a mixture of FYM + Cocopeat + farm

Fig. 12.10 (**a**, **b**) Raised beds for growing cucurbits, chilli and palak and polytunnels (**a**) preparing nursery bed/raised bed with local areca nut stems (**b**) for growing vegetables in Andaman Islands

soil in 1:1:1 ratio (Fig. 12.11). Locally available coconut husk is placed on both sides to reduce the run-off of growing materials from the trenches during heavy rains. It is suitable for growing vegetable crops in protected structures constructed on problem soils. This is particularly useful for growing fast-growing high-value vegetables inside the polytunnels, shade net and open condition. Further, trench system is useful for growing vegetables in problem soils like hilly terrains or seashore areas. These trenches are best option for cultivation of vegetables in problem soils, particularly in polyhouses. Further, youth can adopt this technology as entrepreneurship for supply of essential inputs or services for constructing such structures.

3. Polybag cultivation technique: This technology was found very effective for growing vegetable crops in polyhouses in island condition. In open condition, it has a problem because heavy rains create excess moisture in polybags or wash away the growing media. In areas where soil digging activities are advisable, the polybag cultivation appears as the best alternative. For this, the UV-stabilized plastic bags of 30 × 30 × 30 cm size are filled with growing media Cocopith + FYM + vermin (1:1:1) for growing vegetables in problem lands in home garden or polyhouse (Fig. 12.12). It allows to accommodate more plants per unit area as observed in cauliflower, wherein 70,000–80,000 plants can be accommodated in comparison to 45,000–50,000 plants/ha in conventional method. It is promising for cauliflower, tomato, knol khol, etc. In knol kohl, high yield (16 t/ha) improved quality of tubers than in normal soil conditions (12 t/ha). High yield per unit area, portable system, ease of managing and less use of irrigation water make polybags a better choice for horticultural entrepreneurs in the islands.

Fig. 12.11 Making trenches on uplands in open and growing high-value vegetables

Fig. 12.12 Growing cauliflower and knol khol in polybags in rain shelter in Andaman Islands

12.5.6 Intercropping in Coconut and Areca Nut Gardens

In Andaman and Nicobar Islands, coconut gardens occupy around 21.91 thousand ha area, which remains mostly unutilized due to lack of knowledge on suitable intercrops, risk of crop damages by heavy rains in rainy season and lack of irrigation water in dry season. The productivity of these orchards is also low due to poor management practices. Therefore, we tested three crops, namely palak, poi (Indian

Crop (s)	Yield (t/ha)	
	2012-13	2013-14
Coconut (nuts/palm)	30.0-33.0	32.0-35.0
Palak (sole crop)	10.5	11.2
Palak (in Coconut+Palak)	15.5	18.0
Percentage increase over the open crop	47.6%	60.7%

Source: Singh *et al.* (2014)

Fig. 12.13 Performance of palak as an intercrop in coconut gardens in the islands

spinach) and amaranth, as intercrops in coconut gardens and found the palak as the most remunerative intercrop in coconut plantation during December–March months. In 2-year study, at a farmer's field, it yielded 47.6 and 60.7% higher yield than its sole crop in open field (Fig. 12.13). Besides, the quality of the leaves was also better than open-field cultivation. The participatory trial was on a woman farmer's field, and as per her observation, the coconut yield was slightly improved. For this, land is prepared leaving 1 m circle around coconut and well-decomposed FYM @ 10 t/ha is applied along with 1 t/ha vermicompost. Seeds were sown in rows at 15 cm distance. The plot was applied with vermicompost @ 1 t/ha by broadcasting method. The second crop was harvested 15 days after the first harvest. This study has great prospect to utilize the interspaces in coconut gardens in tropical island regions. It increases the farm income and improves vegetable sector; therefore, this is also a viable income enhancement option for island tribals and coconut plantation owners.

Similarly, initial period of areca nut plantation can be effectively used for growing high-value vegetables such as cauliflower, bush-type French bean, palak and cabbage. Growing of cabbage was very remunerative during dry season. This helps in increasing the farm income and favours fast growth of areca nut plantation (Fig. 12.14a). Further, crop combination, i.e. growing leafy vegetables in between rows of cucurbits, was tested in Andaman condition. For this, seven leafy vegetables were evaluated between the bitter gourd rows (Fig. 12.14b). The highest yield was recorded from the intercrop poi (18.0 t/ha), which was less than the sole crop of poi (24.0 t/ha). Similarly, the yield from all the leafy vegetables was less (18.7–49.2%) from intercropping system due to reduced area effect. The economic analysis estimated the highest net returns from bitter gourd + poi (Rs. 318,000) followed by bitter gourd + amaranth green (Rs. 228,000). Such interventions increase farm income and also expend the period of farm earnings, which are crucial to retain the farming sector viable and attractive, particularly for young farmers.

Fig. 12.14 (**a**) Intercropping of cabbage in areca nut plantation (**b**) and growing Indian spinach in bitter gourd in Andaman Island

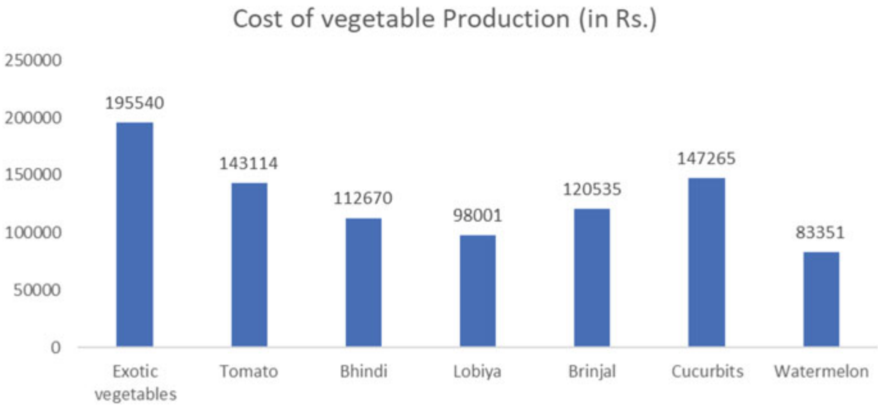

Fig. 12.15 Cost of vegetable production in Andaman and Nicobar Islands (Data source: Basic Statistics 2020)

12.6 Reducing the Cost of Production of Vegetables

The current trend indicates higher cost of cultivation for exotic vegetables and other commercial vegetables in Andaman and Nicobar Islands (Fig. 12.15). However, the price remains high in rainy season, but same trend does not remain in dry phase when vegetable production is high. Thus, cost reduction is possible through promoting on-farm vermicomposting (for nutrient cost reduction), timely identification of disease/pest and management activities (for chemical cost reduction), utilizing interspaces in wider vegetable crops or other perennial crops and effective use of labour through proper planning or integrative activities (for labour cost reduction), proper short-term on-farm or island-wise storage facility (to minimize transport charges), promoting local seed system (to reduce seed cost), promoting yield-maximizing practices for higher yield, etc. Further, the indigenous vegetables remain abundant in rainy season, and their production cost is also low in some crops; it is equal to just the cost of collection because they grow in natural habitats. The indigenous underutilized crops which are adapted to local ecosystem and have certain agro-ecological attributes such as (1) need very less or minimal inputs to grow, (2) naturally propagate or seed produced and shared by growers or sold in local market at very nominal price, (3) over the period these crops acquired adaptive/ resistance mechanism to diseases and insect-pest, so growers/harvesters never or rarely use chemical pesticides, (4) these minor crops row naturally in wild habitats without tillage operations, and (5) they are mostly seasonal harvested in nature and remain associated with certain local delicacies. These agro-ecological attributes make them a good choice for exploring in low-cost farming systems and natural farming systems.

12.7 Tapping the Potential of Perennial Vegetables in the Islands

The islands have rich diversity of tree vegetable species such as *Moringa oleifera*, *Artocarpus heterophyllus*, *A. incisa*, *Murraya koenigii* and *Tamarindus indica*, which are prevalent in home gardens in the ANI (Abraham et al. 2008; Pandey et al. 2006). *Cycas rumphii* and *Calamus andamanicus* are eaten in the form of stew, soup, pickle, chutney or curry (Singh et al. 2018). Perennial vegetables as wild relatives of cultivated species, viz. *S. melongena* and *C. annuum* (Abraham et al. 2008), *Carissa carandas* L., *C. spinarum* L. and *C. andamanensis* L.J., are not exploited so far. Fruit crops for use of vegetable purpose such as vegetable banana, green papaya, carambola and immature green mango are the dependable sources even during climatic aberrations. Nicobari tribes have a mastery in the preparation of delicious food items from bread fruit, jackfruit and kewda (screw pine). These perennial fruit-cum-vegetable plants are very common in Andaman and Nicobar Islands; therefore, they can be explored for their commercial potential for tourists and urbanites and exports. Proper trainings for market-oriented product customization and product certification-related support can be facilitated by the local administration. The islands have about 34 mangrove species, which cover 12% of geographical area, few of them being edible (Goutham-Bharathi et al. 2014). In all, little attempts to document and conserve germplasm resources of perennial vegetable species in the islands invite systematic efforts to explore their potential in the livelihood and nutritional security of dwelling population.

12.8 Strengthening 'On-Site' Production System

The vegetables are perishable food items, and their regular supply in adequate quantity remains a big challenge. Hence, measures to enhance production of vegetables 'in locale' through home gardens, kitchen gardens, container gardening, roof gardening, etc. are essentially required not only for remote rural areas but also for urbanites. Establishment of new home gardens or enriching the existing traditional home gardens with nutrient-rich locally adaptable crops and their superior varieties could contribute much better to the productivity and nutritional security in an environmentally sustainable manner. But this requires identification of region-specific vegetable crops and breeding of varieties for dietary nutrients, prolonged harvest period, adaptation to growing situation and high acceptance among the ultimate beneficiaries. The breeding objectives could include improvement for dietary nutrients and antioxidants, organoleptic scores, tolerance to partial shade, high portion of edible fruits/parts, low gestation period, resistance to diseases and insect pests, tolerance to excess rainfall and salinity, response to organic sources, etc. So far, research efforts have remained targeted towards the development of technologies and varieties for commercial scale, but some varieties are quite fit for small-scale growing in gardens. But efforts are utmost required to develop plant types ideal for home gardens or other micro-scale production systems.

12.9 Indigenous Vegetables for Livelihood and Entrepreneurship

The following activities on indigenous vegetables are directly linked to providing of livelihood option and development of entrepreneurship among the local people:

- Production of indigenous vegetables for local market
- Production of quality planting material for local and national needs
- Growing and marketing of traditional crops having novel traits
- Promotion of intercropping in coconut, areca nut and fruit plantations and exploitation of the 'zero land cultivation' concept for supplementing local income
- Promotion of tropical biofortified tuber crops, especially climate-resilient traits
- Promotion of protected cultivations (i.e. shade net) of selected crops for meeting the high-end emerging tourism sector and other sectors
- Promotion of biotic and abiotic stress-resistant varieties from similar regions after proper quarantine testing
- Local human resource creation for vegetable sector by creating local training centres
- Tapping potential of local crops for high-end food industry—nutraceuticals and functional foods
- Sensitizing and marketing of local rare crops having a strong traditional value in different forms
- Local food outlets for tourists and urbanites with reliable and healthy cooking practices
- Processing and packaging of local unique IVs for national market
- Integration of vegetables (particularly IVs) in IFS system-potential component

12.10 Conclusion

Indigenous vegetables are an important and easily available diet component in tribal and rural communities, while exotic vegetables play a vital role in enhancing productivity and profitability of the farm. It also helps in generating livelihood opportunity to more than 50% of island population, which depends on agricultural activities. The indigenous vegetables favour ecosystem diversity and require less use of tillage and chemical inputs, which contributes to the ecosystem equilibrium. In contrary to this, the exotic vegetables are grown with intensive tillage practices, and frequent use of chemical pesticides could hamper the quality of soil and water bodies. As both groups of vegetables are inevitable in the context of island, a rational approach needs to be adopted, wherein indigenous vegetables get adequate space in emerging market while exotic crops add value to island economy through attracting tourists and floating populations. Thus, promotion of nutritious IVs in home gardens, kitchen gardens, community gardens and school gardens and enriching of natural habitats are necessary to increase household intake as well as to meet the local market demand. The work done by CIARI in Car Nicobar and Little Andaman through an ICAR-sponsored Tribal Sub Plan (TSP) scheme during 2013–2015 has shown promising results for participatory improvement of production and acceptance of different IV crops in the region. We could notice that the IVs and communities change with region, so there is a need to document the use pattern and nutritional potential of such crops at university/institute level with involvement of NGOs. It is also suggested to integrate the selected indigenous vegetables in Mid-Day Meal Scheme, Integrated Child Development Programme and *Anganwadi* Scheme for exploiting their nutritional health benefit for children and women in particular. Further, there is a need to promote IVs in selective food items by providing outlets at tourist sites or other prime localities. However, it is also essential to give attention for conservation and genetic improvement of prioritized IVs for uniformity, consumer traits, yield, nutrients, etc., developing seed and marketing facilities. These crops have issues related to anti-nutrient factors, which need proper attention of processing experts and breeders. The role of indigenous crops in mitigating climate change impact has been found at great extent; however, it needs further systematic studies.

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Off-Season Vegetable Growing for Nutrition and Entrepreneurship

13

Akhilesh Sharma, Hem Lata, Pankaj Sood, Alisha Thakur, K. C. Sharma, and Parveen Sharma

Abstract

Vegetables are wholesome foods which are an essential part of a healthy diet and provide micronutrients, vitamins, minerals, dietary fibre and phytochemicals in a balanced form. There is year-round demand for fresh vegetables, but supply is limited to cultivation season. Three hill states of India, viz. Jammu and Kashmir, Uttarakhand and Himachal Pradesh, fall under North-Western Himalayan region and have emerged as 'Natural Glass House' of the country with diverse climate ranging from subtropical to dry temperate and therefore have become the hub of off-season vegetable cultivation. Topographic factors in hills, viz. altitude, latitude and slopes, make the valley in hills suitable for raising off-season vegetables. The hill-grown vegetables find favour for their flavour, freshness, crispness and sweetness, superior quality and pesticide residue free. The winter-season vegetables are produced during summer season in hills and find ready market in the plain, bringing lucrative returns to farmers during their lean period. The vegetables that have earned name in the production of off season in hills are tomato, green peas, beans, cabbage, cauliflower, green capsicum, coloured capsicum, summer squash, cucumber, broccoli, lettuce, Chinese cabbage, Brussels sprouts, European carrot and snow peas. Off-season vegetable cultivation through

A. Sharma (✉) · H. Lata · A. Thakur · P. Sharma
Department of Vegetable Science and Floriculture, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh, India

P. Sood
KVK, Sundernagar (Mandi), Himachal Pradesh, India

K. C. Sharma
KVK, Bajaura (Kullu), Himachal Pradesh, India

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protected structures also provides an opportunity to rural youths. Furthermore, there is a significant scope for crop diversification through off-season vegetables due to a wide variety of agro-climatic and soil type conditions. Production of vegetables in these states ensures the regular supply of fresh vegetables, increases the total vegetable production, offers more choices to consumers and makes the production system economically sustainable and remunerative.

Keywords

Crop diversification · North-Western Himalaya · Nutrition · Off season · Vegetables · Remuneration · Self-employment

13.1 Introduction

Vegetables are the important source of nutritional security and are essential for well-balanced human diet. They are the food basket of the people, and along with overcoming hunger, they also provide essential vitamins, minerals, micronutrients and phytochemicals that have medicinal properties. India, being a vast country with diverse and extreme agro-climatic conditions, contributes about 13% of the total world production of vegetables. In 2010–2011, the area covered by vegetable crops in India was 8495 thousand hectares with the production and productivity of 146,555 thousand metric tonnes and 17.25 metric tonnes per hectare, respectively. The area under vegetables during 2019–2020 was estimated to be 10,353 thousand hectares with an annual production of 191,769 thousand metric tonnes and productivity of 18.52 metric tonnes per hectare (Table 13.1). This shows an immense growth in area and production under vegetable crops in India for the last 10 years with an increase of 21.87% in area and 30.85% in production (Table 13.2). The annual growth both in area and production of vegetables has gained considerable momentum in the wake of off-season cultivation. With this evident increase, India has bagged the second

Table 13.1 Area, production and productivity of vegetables in India for the last 10 years

Year	Area ('000 ha)	Production ('000 MT)	Productivity (MT/ha)
2010–2011	8495	146,555	17.25
2011–2012	8989	156,325	17.89
2012–2013	9205	162,187	17.62
2013–2014	9396	162,897	17.33
2014–2015	9494	167,058	17.59
2015–2016	9575	166,608	17.40
2016–2017	10,238	178,172	17.40
2017–2018	10,259	184,394	17.97
2018–2019 (estd.)	10,073	183,170	18.18
2019–2020 (estd.)	10,353	191,769	18.52

Source: Horticultural Statistics at a Glance (2018)

Table 13.2 Growth in area and production of vegetables over the last 10 years

Year	Area (%)	Production (%)
In 2011–2012 over 2010–2011	5.82	6.66
In 2012–2013 over 2011–2012	2.40	3.75
In 2013–2014 over 2012–2013	2.07	0.44
In 2014–2015 over 2013–2014	1.04	2.55
In 2015–2016 over 2014–2015	0.85	(−)0.27
In 2016–2017 over 2015–2016	6.92	6.94
In 2017–2018 over 2016–2017	0.21	3.49
In 2018–2019 over 2017–2018	(−)1.81	(−)0.66

position after China in the production of vegetables in the world. India is now the leading producer of peas and okra; second largest producer of brinjal, cabbage, cauliflower and onion; and third largest producer of potato and tomato in the world. Though India is the second largest producer of vegetables in the world, the production is not enough to meet the daily requirement of vegetables of an individual. Various noticeable efforts need to be made to increase the area and production under vegetables by making use of hybrid seeds and different improved agro-techniques and promoting off-season cultivation of vegetables.

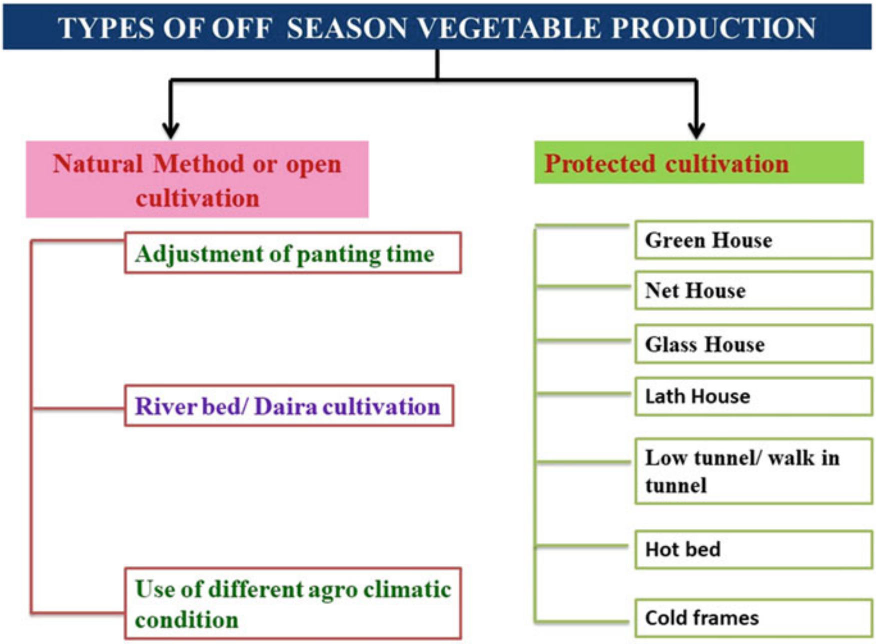
13.2 Off-Season Vegetable Cultivation

The cultivation of crops outside their regular cropping calendar, i.e. after or before their normal season, is called off-season cultivation. The main objectives of off-season vegetable cultivation are the production and supply of vegetables during their lean period, self-employment/entrepreneurship and encouraging youth to take up agriculture as an opportunity. Owing to diverse climatic conditions, the vegetables that are produced in one agro-climatic region during their normal season of cultivation can be sold to other areas as off-season vegetables where these vegetables cannot be grown during that period. High demand of off-season vegetable cultivation can play an important role in boosting the production of vegetables in the country. It ensures the regular supply of fresh vegetables, offers more choices to consumers and increases the income of farmers in rural areas by generating self-employment opportunities.

The main purpose of off-season vegetable farming is to produce and supply vegetables to the market during their lean period. The vegetables that have earned name in the production of off season are tomato, garden pea, beans, cabbage, cauliflower, capsicum, coloured capsicum, potato, garlic, onion, summer squash, cucumber and many other exotic vegetables. Exotic vegetables like asparagus, broccoli, lettuce, celery, Chinese cabbage, Brussels sprouts, European carrot, parsley, leek, Swiss chard and snow peas are also gaining popularity in hilly areas, particularly as off-season vegetables. Off-season cultivation is also profitable in many other aspects like exploitation of agro-diversity, better utilization of land and farm resources, better revenue, self-employment, entrepreneurship, possibility of export and earning of foreign exchange. Furthermore, in the absence of storage infrastructure and vegetable processing industry in the country, off-season vegetable farming is the only viable option that can add value to the farmer produce (Bhardwaj 2012).

13.3 Types of Off-Season Vegetable Cultivation

Off-season vegetables can be produced through natural method or open cultivation by availing different agro-climatic conditions, adjusting the sowing time, selecting and improving the varieties and riverbed/diara cultivation. Vegetables are grown during normal season in one climatic region and marketed as off season in another climatic region. For example, in high altitudes of Himachal Pradesh and some parts of Uttarakhand, farmers produce cauliflower, cabbage, radish, leafy vegetables and peas during summer and rainy seasons and supply to the markets of Dehradun, Delhi and Chandigarh as off season. The use of improved varieties which can avoid or tolerate the limiting factors can prolong the production and supply demand. For example, in cauliflower, an early cultivar Pusa Deepali becomes ready to harvest in September when planted early, whereas Snowball-10, a late variety, becomes ready for harvesting in January–February. Diara land farming or riverbed cultivation is a very old practice of growing vegetables on the bank or basin of a river after the flood level recedes. Cucurbits are specially adapted to this system of growing due to their long taproot system. It can be treated as a kind of vegetable forcing wherein the cucurbits are grown under subnormal conditions, on sand, during winter months from November to February, especially in North and North-Western India. Riverbed farming can be used to increase household income and to improve the food security of landless and land-poor households in coastal areas.



Hill topography in North-Western (NW) Himalaya limits the possibility of increasing the cropping area and farm profits. Off-season vegetable is a promising technology for doubling farmers' income by adopting proper protection technologies and providing favourable environment to crops and better livelihood to hill farmers. With the development in agriculture, a number of protective cultivation practices suitable for a particular type of agro-climatic zone have emerged. In protected cultivation, climate surrounding the plant is controlled partially or fully, as per the requirement of the plant, during their period of growth and plants get protected from adverse conditions like sunburn, rains, hailstorm, freezing temperature, insect, pest and diseases. In controlled environment, vegetables are cultivated by utilization of protected structures, viz. polyhouse, shade net, plastic low tunnels, greenhouse, permanent glasshouse and insect-proof net (Sindhu and Chatterjee 2020).

Proper selection of crops and adoption of appropriate protected structures offer advantages of high productivity and ensure better quality and profit maximization by providing favourable market price to the grower. Tomato, capsicum and cucumber are the most extensively grown vegetables under greenhouses and give higher returns (Chandra et al. 2000). Negi et al. (2013) found that in shade net, the percentage of yield increase was maximum for pea (286%) followed by capsicum (70%) and tomato (58.66%).

Off-season cultivation of cucurbits under low plastic tunnels is one of the most money-making technologies under northern plains of India. Walk-in tunnels are efficient means to raise off-season nursery. Insect-proof net houses provide virus-free conditions for production of vegetables during the rainy season. Poly-trenches have been proved to be tremendously useful for the production of vegetables under cold desert conditions. Therefore, protected cultivation of vegetables enables us to grow vegetables at par with any climatic conditions and leads to the production of off-season vegetables.

13.4 North-Western Himalayan Region of India as Natural Glass House for Off-Season Vegetable Cultivation and Crop Diversification

Agriculture is the backbone of rural livelihoods in the North-Western Himalayas (NWH); more than 80% of farmers in the mountain region of NWH are small landholders (Choudhary et al. 2012). The crop diversification has made a great effect on the quality of life of nurturing these households. The crop diversification in relation to selective high-value crops including fruits and vegetables, compatible with the relative advantage of the region, is an effective strategy in generating employment opportunities, raising incomes and alleviating poverty among small farmers (Joshi et al. 2004).

Vegetable farming has emerged as an alternative cash crop for farmers of three hill states of India, viz. Himachal Pradesh, Uttarakhand and Jammu and Kashmir, falling under North-Western Himalayan region. The statistics of vegetable cultivation of these states has been depicted through Fig. 13.1 and Table 13.3. The majority of marginal and small farmers used to do traditional farming, which was not so remunerative because of low crop productivity and profitability. These hill areas act as a natural glass house of the country for vegetable production as farmers have come forward to cultivate off-season vegetables. Topographic factors in hills, viz. altitude, latitude and slopes, make the valley in hills suitable for raising off-season vegetables. These areas possess a vast potential and serve as a greenhouse for growing off-season vegetables on a commercial scale to bridge the season interval and also the gap between demand and supply. In this reverence, more emphasis needs to be given on the extension of its cultivation in unexplored valley of the country.

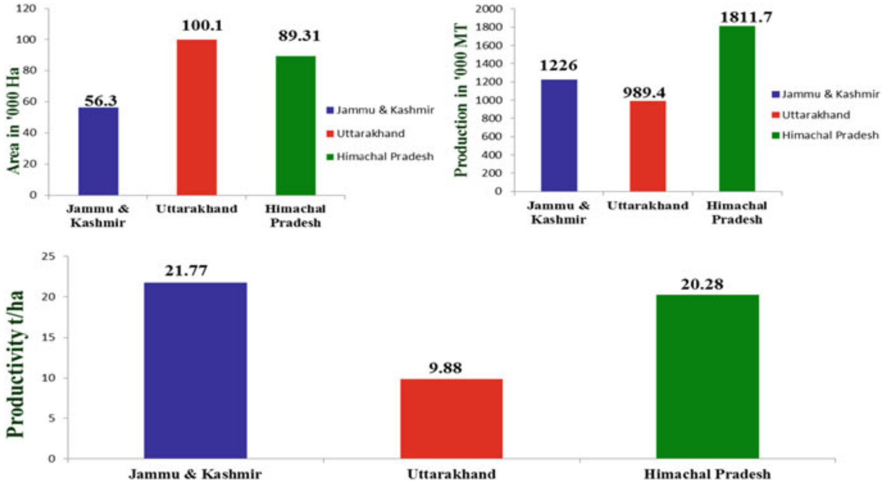


Fig. 13.1 Area, production and productivity of vegetables in North-Western Himalayas

In mountain areas, there is a large scope for diversification through vegetables and other farm enterprises due to a wide variety of agro-climatic conditions and soil types that enable the cultivation of various vegetable crops (Choudhary et al. 2013). In Himachal Pradesh, the area under vegetable crops has increased from 67.69 thousand hectares (2011–2012) to 89.31 thousand hectares (2017–2018) due to crop diversification. The trend of area under diverse vegetable crops has also witnessed a rapid increase in recent years (Fig. 13.2).

In Kullu district of Himachal Pradesh, the cereal-dominated cropping pattern was replaced by vegetable-based cropping pattern, since the area under cereal crops declined, and cropping intensity also increased from 197% to 225% (Bala and Sharma 2005). Crop diversifications make available an indirect assurance against a number of vagaries affecting monoculture and thus increase the income base of the rural farmers in hilly regions. Improvement in income is essential to people in hilly areas of the country that are very much reliant on farming. Further, they have a low proportion of land under agriculture; for example, in Himachal Pradesh, only 11% of the total area is under agriculture. Thus, specific utilization of potential for agriculture through off-season vegetable cultivation can add beneficial income and provide advantage of crop diversification (Dhanta and Negi 2018). Government has played a very crucial role in promoting the crop diversification in NWH states and initiated an ambitious plan to the farming community for adopting new cropping pattern, and many agrarian projects have been executed. As a result, the mountain agriculture is shifting from traditional cereal farming to high-value cash crops, and cropping pattern in cold climatic regions has undergone a tremendous change with the introduction of off-season vegetable crops (Choudhary 2016). The off-season vegetable cultivation in Kullu district of Himachal Pradesh has revolutionized the status of hill farmers, which can be noticed from the economics of raising different vegetable-based sequences (Table 13.4).

Table 13.3 Area and production of major off-season vegetables in North-Western Himalayas

	Himachal Pradesh			Jammu & Kashmir			Uttarakhand		
Crop	A	P	Pt	A	P	Pt	A	P	Pt
Cabbage	4.90	168.25	34.32	3.79	114.70	30.29	6.35	67.89	10.69
Cauliflower	5.56	131.01	23.55	3.40	105.40	31.02	3.18	41.97	13.18
Peas	24.37	294.96	12.10	2.38	30.82	12.93	13.09	93.40	7.14
Radish	1.95	40.89	20.97	2.77	65.16	23.52	5.21	59.90	11.50
Carrot	0.38	7.67	20.18	1.86	32.41	17.42	–	–	–
Potato	15.88	198.66	12.51	5.17	110.24	21.32	26.31	362.16	13.76

Source: Horticulture Statistics at a Glance
Area in '000 ha (A); production in '000 MT (P); productivity in MT/ha (Pt)

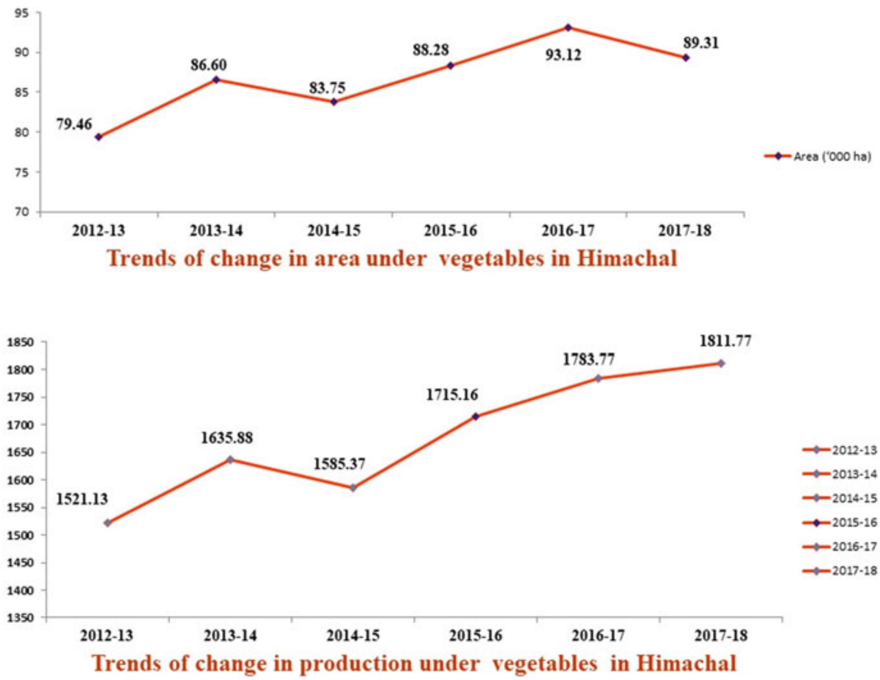


Fig. 13.2 Trends of change in area and production of vegetable crops in Himachal Pradesh

Table 13.4 Major vegetable-based sequences in the district Kullu (HP) and their economics (Source: KVK, Kullu, HP)

Sequence	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C ratio
Tomato (April)-bean (August)-peas (October)	789,000	628,000	3.86
Tomato (March)-cucumber (July)-peas (November)	1,024,000	825,000	4.38
Capsicum (April)-cauliflower (July)-radish (November)	605,000	448,000	3.85
Tomato (May)-garlic (October)	560,000	434,728	4.08

13.5 Climate of Hills: A Boon for Better Quality and Nutritious Vegetables

Topographic factors in hills, viz. altitude, latitude and slopes, make the valley in hills suitable for raising off-season vegetables. Temperature impacts photosynthesis, water and nutrient absorption, transpiration, respiration, enzyme activity, germination, flowering, pollen viability, fruit set, rates of maturation yield, quality, harvest duration and shelf life. Vegetables grown in the Himachal are known for their flavour, freshness, sweetness and crispness due to which they remain in great demand in plains. The cooler temperatures result in long growing period, prolonged harvest duration and accumulation of more photosynthates, and thus the crops possess high nutrient profile compared to those in plain areas. The climatic conditions favour better growth and comparatively low incidence of diseases and insect-pests, which provides pesticide residue-free vegetable produce, which is an additional advantage. Intensity of sunlight increases with increase in altitude. Increase in light intensity increases ascorbic acid and thiamine content of vegetables, e.g. tomato, lettuce and sweet pepper. Better lycopene is found in tomato fruits. Optimum and better relative humidity helps in quality vegetable production at different locations.

13.6 Himachal Pradesh: Hub of Off-Season Vegetable Cultivation

Himachal Pradesh finds a very coveted position in the country for off-season vegetable production and is known as a natural greenhouse due to diverse climate ranging from subtropical to dry temperate that facilitates year-round production of vegetables in one or the other region. This provides an opportunity for majority of the vegetables to be available in the lean period when supply is restricted from northern Indian plains. Majority of cool-season vegetables are raised during summer season in high hills and have monopoly in the plain markets for peas, cole crops, root vegetables, lettuce, celery, parsley and many other European vegetables. During rainy season, hilly terrain provides natural drainage and thus provides availability of quality produce of tomato, bell pepper, beans and cucurbits at premium price. Exotic vegetables like asparagus, broccoli, lettuce, coloured capsicum, celery, Chinese cabbage, Brussels sprouts, European carrot, parsley, leek and snow peas are also becoming popular. The vegetables significantly contribute to the revenue generation in Himachal Pradesh (Fig. 13.3).

The availability of vegetable produce from hills in comparison to plains (Table 13.5) clearly depicts the importance of vegetables as off season providing high remuneration when supply in the plain markets is limited and demand is static throughout the year. Solan, Mandi, Shimla, Sirmaur, Kullu, Lahaul and Spiti, Kinnaur and Kangra districts are the main production centres of off-seasonal vegetables in the state.

13.7 Off-Season Vegetable Cultivation as Self-Employment for Rural Youths

In India, North-Western Himalayas are home for cultivation of all types of vegetables. Hill terrains are more productive for growing various vegetables than the plains due to better environmental conditions and proper drainage during the

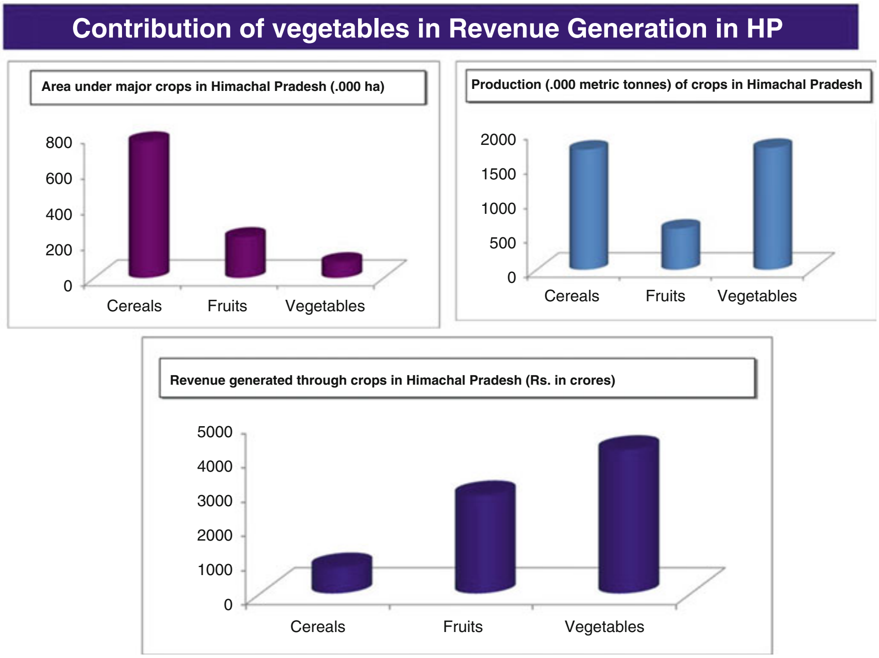


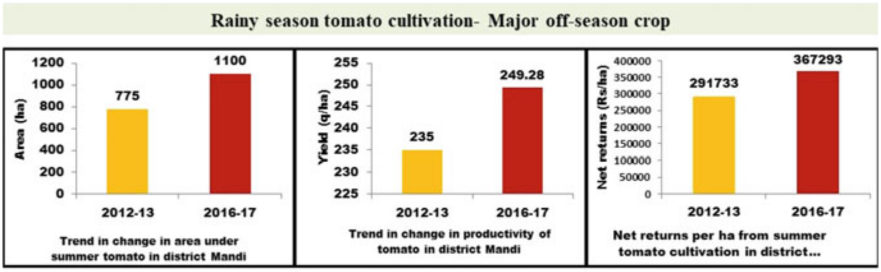
Fig. 13.3 Contribution of vegetables in revenue generation in Himachal Pradesh

rainy season. Thus, adopting off season in the Himalayan mountains provides an opportunity to improve the income of farmers by offering self-employment and plays an important role in the sustainable livelihood of hill people. In Himachal Pradesh, several vegetables grown in the summer season and *kharif* season are harvested at a time when they cannot be produced in the plains. Off-season vegetable production and marketing are the most profitable farm business giving very high production and income to farmers per unit area of land (Thakur et al. 1994). Off-season vegetable cultivation transforms rural economy in Himachal Pradesh. The estimates indicate that off-season vegetable growing provides average net returns of Rs. 60,000 to Rs. 2 lakhs per hectare as compared to Rs. 8000 to Rs. 10,000 per hectare from traditional crops. Farmers grow 'off-season and exotic vegetables' by adopting modern farm techniques and best use of highly subsidized schemes for polyhouses, micro- and flow irrigation, plant protection, quality seeds, capacity building and institution strengthening. In Himachal Pradesh, total vegetable production during the year 2019 reached 1.81 MT from 88,367 ha area. Vegetable production is generating a revenue of Rs. 3500–4000 crores annually and has emerged as an alternate economic activity in the horticulture belt. Sati (2007) reported that in Uttarakhand, even the area under vegetables was less than the traditional crops but the production and productivity were comparatively high. Moreover, off-season cultivation of vegetables makes people self-sufficient and provides high remunerations along with generating employment opportunities.

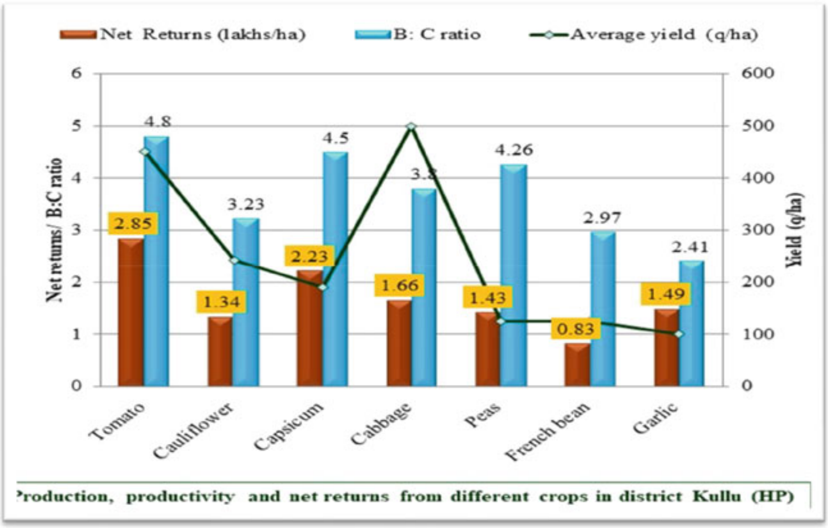
Table 13.5 Availability of commercial vegetable produce of important vegetable crops in hills compared to normal season in plains

Crop	Region	Sowing season	Availability of vegetable produce	Normal season in plains
Garden pea (major off-seasonal vegetable)	Mid- and high hills of Kullu, Shimla, Solan, Kangra and Mandi	Winter	March–May	January–Early March
	High hills—dry temperate zone in Lahaul and Spiti and Kinnaur	Summer	June–September	–
	High hills, wet temperate zone: Kullu, Shimla, Chamba and Mandi	Rainy season	September–October	
	Low hills—Una, Hamirpur, Kangra	Autumn season	November–early December	October–November
Cole crops Root vegetables Leafy vegetables Salad crops	Mid- and high hills (dry and wet temperate)	Early spring/summer	April–September/October	–
	Low hills	Rainy/autumn	August–December	September–November
Tomato and bell pepper	Mid-hills (Kullu, Mandi, Sirmaur, Solan, Shimla)	Spring, summer and rainy	June–October/November	March–May
Cucurbits and okra	Mid- and low hills	-do-	April–October	March–June
French bean	High, mid- and low hills	-do-	April–December	March–mid-April

Paul et al. (2020) studied the income and employment potential of selected vegetable and worked out highest for tomato (Rs. 331,893/ha) followed by capsicum (Rs. 229,802), cabbage (Rs. 190,340), cauliflower (Rs. 159,254) and peas (Rs. 89,803), and the gross annual income per hectare was highest in case of small farms (Rs. 446,586) as compared to other groups of farms. In mid-hills of Himachal Pradesh, off-season vegetables like garden pea, beans, cauliflower, cabbage, radish, turnip, carrot and garden beat are more profitable crops. Being labour intensive, it also offers better employment opportunities as all the operations need to be done manually due to tough terrain and scattered landholdings. It facilitates better utilization of farm resources as they are more efficient converters of farm resources than other crops in terms of yield per unit area and per unit time since they grow very fast. It also results in better utilization of land under young orchards. The space in between fruit plants and row in young orchards of apple, peach, plum and walnut are being used for raising off-season vegetables like cabbage, radish and leafy vegetables and can earn income till the orchards start bearing fruits with additional income. Thereby, it intensifies the vegetable cultivation, with better light utilization and increase in the cropping index by multiple cropping (Singh 2000).



Source:KVK, Mandi



The cultivation of vegetables under different kinds of protected structures, the most common being one's natural ventilated polyhouses in these states, also provides better opportunities to the rural youths by providing high production and net returns per unit area, which are about 3–5 times higher than those in the field conditions (Table 13.6).

13.8 Off-Season Vegetables for Human Nutrition

Nutrition data in developing countries like India indicates that hidden hunger, a form of micronutrient malnutrition, is alarmingly prevalent in farming households. However, among the most critical imperceptibly focused developmental challenges is malnutrition. Though the rate of malnutrition in the country has dropped down so far, it is still prevalent in 51% of the stunted and 49% of the underweight children in

Table 13.6 Comparative performance of crops under protected and field conditions (Source: KVK, Mandi)

Particulars	Protected conditions			Field conditions		
	Tomato	Capsicum	Cucumber	Tomato	Capsicum	Cucumber
Productivity (t/ha)	110.0	75.0	110.0	50.0	30.0	50.0
Gross return (Rs. in lakhs)	22.0	22.5	16.5	10.0	6.0	7.5
Net profit (Rs. in lakhs)	15.70	17.65	13.45	6.00	3.95	4.50

the lowest income families. Today, India is home to the majority of stunted (46.6 million) and wasted (25.5 million) children in the world. Despite several attempts and programmes to improve the nutritional status of India, nutrition and stunting still prevail as a barricade for the country. India ranks 102 among 117 countries in the Global Hunger Index (GHI) of 2019, with the maximum of the world's undernourished population. Nutrition and stunting have numerous implications on the human education, capital and poverty abatement, thus worsening the economic growth and development of the country.

A proper balanced diet is the key to provide nutritional security. With Green Revolution, many productive varieties of wheat and rice were developed that increased the food supply in the world and brought a ray of hope to eradicate food insecurity in the world. There is deficiency of vitamins, minerals and micronutrients in the cereal based diet of people in the developing countries. Cereal-based nutrition of the people in developing countries are deficient in vitamins, minerals and micronutrients. In consort with grains and cereals, vegetables constitute a major part in a balanced diet of a human being. Vegetables are a major source of micronutrients, vitamins, minerals, dietary fibre and phytochemicals that have medicinal and anti-cancerous properties, thus protecting against the free radical damage. Additionally, vegetables supply dietary fibre, and fibre intake is linked to lower incidence of cardiovascular disease and obesity (Slavin and Lloyd 2012). These are the best resource for overcoming micronutrient deficiencies, and due to these benefits, vegetables are well known as 'protective foods' (Nisha et al. 2017). According to the ICMR, the daily requirement of vegetables has increased from 264 g/person/day in 2004–2005 to 393.76 g/person/day in 2017–2018, but the requirements are not being fulfilled which is the major challenge. Low vegetable consumption could increase the risk of several noncommunicable diseases like coronary heart disease and stroke and risk of different types of cancers (Institute for Health Metrics and Evaluation 2017). Vegetables are the primary source of some essential nutrients, i.e. fibre, folate and several vitamins. Reduced vegetable and legume consumption could also lead to nutrient deficiencies, and it is hard to overcome through substitution with other foods. Adequate consumption of nonstaple vegetables and legumes is a fundamental recommendation in all national and international food-based dietary guidelines (Uauy et al. 2014). Therefore, ensuring sufficient availability of, and access to, vegetables and legumes represents an urgent global nutrition and public health challenge (Pauline et al. 2018). Worldwide per capita consumption of vegetables and fruits is 20–50% below the minimum daily recommended level, although large regional differences exist (FAO 2013).

Vegetables are rich in phytochemicals, which are used for a number of purposes such as pharmaceuticals, agrochemicals, flavours, colouring agents, aroma, bio-pesticides and food additives. They impart health benefits to humans due to high antioxidant activity and also have many antibacterial, antiviral, antifungal, cholesterol-lowering or anti-inflammatory effects. Secondary metabolites present in plant foods are alkaloids, and phenolic compounds, viz. flavonoids, isoflavonoids, anthocyanins and terpenoids, have gained importance because of their antioxidant and antimicrobial effects. Antioxidants in vegetables have a protective effect and include vitamins, phenolics and carotenoids. Vitamin C, carotenoids and phenolic compounds prevent cancer, cardiovascular disease and cataracts, which are associated with the oxidative damage of lipids, DNA and proteins. Anthocyanin is a group of naturally occurring pigments responsible for the purple, red and blue colours of vegetables. The vegetables with deeper and brighter colours or with stronger flavours are often the best sources of phytochemicals with potent nutritional and health-promoting effect. Coloured vegetables like orange carrot, purple cabbage, cauliflower, carrot and red tomato are rich sources of antioxidants and possess anti-cancerous properties. Broccoli, cabbage, collard greens, kale, cauliflower and Brussels sprouts contain powerful phytochemicals, including carotenoids, indoles, glucosinolates and isothiocyanates, which have been studied and shown to slow the growth of many cancers (Table 13.7).

Majority of cool-season vegetables are raised during summer season in high hills and thus ensure the availability of vegetables during off season also. Cooler temperature of hilly area results in long growing period and prolonged harvest duration. Vegetables produced in mountain areas are of superior quality with comparatively low incidence of diseases and insect-pests. Intensity of sunlight increases with increase in altitude and results in increase in ascorbic acid and thiamine content of vegetables like tomato, lettuce and sweet pepper. Optimum and better relative humidity helps in quality vegetable production at different locations.

13.9 Challenges

- Tough terrain and poor road connectivity
- Non-availability of quality seeds
- High perishability
- Unorganized market centres
- Farmers not getting premium price—there is a need to eliminate the role of middleman
- Lack of continuous support of improved technologies

Table 13.7 Phytochemicals in vegetables

Vegetables	Compound	Properties
Tomato	β-Carotene, lycopene	Antioxidant, protect the skin from UV irradiation, effective against heart disease
Green pea	Lysine	Helps in body tissue to grow
Snow pea	Lutein, zeaxanthin	Antioxidant, prevention of eye diseases, anti-ageing
Lettuce	Lutein	Antioxidant activity
Radish	Isothiocyanate	Detoxification of enzymes in liver, white blood cells, boosts immunity
Carrot	Anthocyanin, lycopene, β-carotene	Act as free radical scavengers in tissue fluids, protect the skin from UV irradiation
Bell pepper	α -Carotene, β-carotene, β-cryptoxanthin, vitamin C	Antioxidant, reduce breast cancer
Onion and garlic	Allicin, quercetin	Antibacterial, relief in allergy symptom, anti-cancer
Beans	Saponins	Lower cancer risks, and lower blood glucose response
Beetroot	β-Cyanins and β-xanthines	Antioxidant property
Celery	Ferulic acid, luteolin, tocopherol, β-carotene	Antioxidants protect cells, blood vessels and organs from oxidative damage, reduce chronic inflammation
Parsley	Flavonoids, carotenoids, α-pinene, β-pinene and vitamin C	Anti-carcinogenic, protection of the vascular system
Cole crops	Anthocyanin, glucosinolates (kaempferol, quercetin, tocopherol, indole-3-carbinol, sulphoraphane)	Anti-cancer activity, protect from cardiovascular disorders and urinary tract infections

13.10 Future Prospects

There are tremendous opportunities to increase the production and area under off-season vegetables by popularization of high-yielding varieties/hybrids of different cash crops. Introduction of rare/European vegetables can pave way to enhance the income of small and marginal farmers of these states as these vegetables have lots of demand in metropolitan cities and also in other areas as the consumer is becoming more cautious about nutrition to have better health. There is a need to standardize agro-techniques with the emergence of high-yielding hybrids from public and private sectors. Marketing of produce is a major hurdle, which can be improved by setting proper marketing yards.

13.11 Conclusions

The off-season cultivation is one of the best options to increase farm income leading to food, nutrition and ecological security as well as poverty alleviation in the region. Therefore, to enhance income and to ensure nutritional security of small and marginal farmers, off-season vegetable cultivation is found to be an economical and profitable enterprise in the North-Western Himalayan region, particularly for rural youths. The recent technological breakthrough in agriculture has stressed the need for diversification, which suggests that vegetables are likely to offer extremely good opportunities to the economy of farmers as well as state to develop at a rapid speed. Furthermore, vegetables have a rich nutritional value. Their value cannot be overlooked, and hence right estimates of demand and supply are a vital prerequisite for any effective policy. It is important to study the demand and supply scenario of fresh vegetables of Himachal Pradesh being marketed in the neighbouring states like Haryana, Punjab and Delhi and Chandigarh. Commercial vegetable crops being highly labour intensive can help to a great extent in solving the problem of unemployment, and their inclusion in crop rotation can help growers to increase their farming income also. Non-availability of seeds, high perishability, unorganized market centres and premium pricing are some of the challenges in the cultivation of off-season vegetables. The demand of fresh vegetables under shrinking land area, rapid growing population and industrialization forces to think beyond the existing line. For maximum utilization of available land and to enhance the productivity as well as to minimize the use of harmful pesticides, protected structures offer immense scope for farmers. Progressive farmers have started growing exotic vegetables by adopting modern farm techniques and making best use of highly subsidized schemes such as polyhouses, micro- and flow irrigation, plant protection, quality seeds, capacity building and institution strengthening, which pave way to others to adopt such technologies for their better livelihood.

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Capsicums for Nutrition and Entrepreneurship

14

K. Madhavi Reddy

Abstract

Chilli (*Capsicum* sp.) is an important vegetable-cum-spice crop cultivated extensively in India. Capsicums are rich in nutrition such as carotenoids, capsaicinoids, vitamins A, C and provitamins E, P, B1, B2 and B3. They are also rich in steroidal alkaloidal glycosides (solanine and solasodine) and scopoletin (coumarin). Capsicums have high medicinal value and are also being used in Ayurveda due to its health benefits. Capsaicin helps in preventing colds, reduces inflammation and promotes capillary and circulatory health. Carotenoids are increasingly drawing the attention of researchers as a major natural food colour due to their inherent nutritional characteristics and the implicated possible role in the prevention and protection against degenerative diseases. Chilli is a cash crop providing lot of opportunities in seed and seedling business, exports, and food, pharmaceutical and solar cell industries.

Keywords

Capsicum · Capsaicin · Carotenoids · Medicinal value · Food and pharmaceutical industry

14.1 Introduction

The origin of chillies is believed to be as old as 7000 BC in Central America and is being cultivated from 3500 BC. Mexicans used it to spice up their food. Chilli was brought to the rest of the world by Christopher Columbus who discovered America

K. M. Reddy (✉)
Division of Vegetable Crops, ICAR-IIHR, Bengaluru, Karnataka, India

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in 1493. Christopher had set from Spain to reach India to bring spices such as black pepper to his country. Christopher not only mistook America for India, but also mistook chilli as the black pepper. That is how the chilli got the name ‘chile pepper’. He took chile pepper back to Spain where it became a very famous spice. Chilli got introduced to India in 1498 and has become an indispensable commodity in the Indian cuisine due to its pungency, spicy taste, appealing colour and flavour. *Capsicum* is a versatile plant being grown as a vegetable and spice crop. *Capsicum* belongs to the family Solanaceae and contains about 22 wild species, and of them five, viz. *C. annuum, C. frutescens*, *C. baccatum*, *C. chinense* and *C. pubescens*, are domesticated species. Major cultivable species *C. annuum* includes chilli/chili, hot pepper, bell/sweet pepper, bird’s-eye pepper, paprika, pickle or stuff-type chilli, squash type and tomato chilli. *Capsicum* terminology is complex having several names worldwide—chile (Mexico), chilli (American English), aji (West Indies/ Carib), pimiento (Spanish), red pepper and pepper (British English), peperone (Italian), piment (French), paprika (German and Northern Europe), biber (Turkish), etc.

India is the largest producer, consumer and exporter of chilli in the world. Total area of chilli cultivation in India is 11.06 lakh ha (8.14 lakh ha under dry chilli and 2.92 lakh ha under green chilli cultivation). Chilli is one of the top most foreign exchange earners of spices and has earned Rs. 8429.92 crores during 2020–2021. Chilli is grown throughout the country.

14.2 Genetic Diversity

Due to continuous cultivation of chilli for about 500 years and its natural cross-pollination tendency, wide range of variability exists in India and is considered as the secondary centre of origin. Chilli has become an indispensable commodity in the Indian cuisine. In India, being the secondary centre of origin for *Capsicum* sp., a wide range of diversity especially with respect to varied fruit colours and pungency exists.

Some of the popular landraces/farmers’ varieties being cultivated in India state-wise are Bhut/Naga jolokia (NE), Byadagi Dabbi/Kaddi (Karnataka), Guntur Sannam (AP), Jwala chillies (Gujarat), Mathania chilli (Rajasthan), Mundu/Gundu Molzuka (TN), tomato chilli/Warangal Chappatta (AP), bird’s-eye/Dhani chilli (NE), Bhiwapur chilli (MH), Hindupur chilli (AP), Kanthari chilli (Kerala), Kashmiri chilli (J&K), Sankeshwar chilli (MH), Nalcheti chilli (MP) and Dharwad/ Tarihal local (Karnataka). So far, the chilli varieties with GI Tag are byadagi chilli, Guntur Sannam chilli, Naga/Mizo chilli and Bhiwapur chilli.

Germplasm diversity of *Capsicum* sp.

14.3 Capsicums for Nutrition

Capsicums are rich in carotenoids (capsanthin, capsorubin, carotene and lutein). Lutein is a xanthophyll and one of 600 known naturally occurring carotenoids. Capsicums are rich in proteins, fats, vitamin A and vitamin C—protein 1 g, total fat 0.21 g, saturated fat 0.031 g, vitamin A 200 IU and vitamin C 183.5 mg/100 g; they are also rich in capsaicinoid oleoresin. Pepper spray, also known as oleoresin capsicum spray, is a lachrymatory agent (a chemical compound that irritates the eyes to cause tears, pain and temporary blindness) used in policing, riot control, crowd control and personal self-defence. Capsicums are rich in provitamins E, P, B1, B2 and B3—vitamin E is an antioxidant that occurs naturally in foods; vitamin P is an antioxidant, associated with ageing, cellular damage and conditions like cancer, Parkinson's disease, asthma, ulcers and allergies, among others. It also helps prevent cold, reduces inflammation and promotes capillary and circulatory health. Capsicums are also rich in steroidal alkaloidal glycosides (solanine and solasodine) and scopoletin (coumarin) too.

14.3.1 Capsicums Rich in Medicinal Value

- They help in keeping cholesterol under control.
- They control blood pressure and prevent cancer.
- The rich vitamin C content present in it mainly prevents blood clotting.

- Regular consumption of *capsicum* is beneficial for those suffering from diabetes.
- *Capsicum* stimulates stomach secretions and improves digestion.
- *Capsicum* is good for those suffering from constipation.
- *Capsicum* can also be used for treating arthritis, sore back muscles, rheumatism or sprains and bruises.
- It is proved to control cold and fever.
- It is also used for *ornamental purpose*, which plays an important role in human health and psychology (as it increases positive energy and reduces stress levels).

14.3.2 Health Benefits of Red Chilli in Ayurveda

- Fights inflammation
- Natural pain relief
- Cardiovascular benefits—with chilli-containing diet, the rate of oxidation (free radical damage to cholesterol and triglycerides) was significantly lower compared to bland diet
- Clears congestion
- Boosts immunity
- Helps to stop the spread of prostate cancer
- Prevents stomach ulcers
- Helps lose weight—increases thermogenesis (heat production) and oxygen consumption
- Lowers the risk of type 2 diabetes

14.3.3 Worldwide Demand for Peppers Is Rising Due to Its Wide Application of Bioactive Compounds in Food and Pharmaceutical Industries

Peppers contain thousands of chemicals including water, fixed (fatty) oils, steam-volatile oil, carotenoids, capsaicinoids, resin, protein, fibre, mineral elements and vitamins. The two most important groups of chemicals found in peppers may be the carotenoids and the capsaicinoids. The carotenoids contribute to pepper's colour and its nutritional value. The capsaicinoids are the alkaloids that give hot peppers their characteristic pungency, which is unique to the species having medicinal value. However, the existence of wide variability for health-related metabolites in germplasm of chilli has not been explored fully.

- Fruit biochemical compounds, carotenoids and capsaicinoids have wide applications in the food, medicine and pharmaceutical industries.
- Chilli fruits are a very rich source of health-promoting bioactive compounds such as carotenoids (lutein, capsanthin, capsorubin, zeaxanthin, violaxanthin, etc.), ascorbic acid, tocopherols and capsaicinoids.

- Many of these compounds are antioxidants and free radical scavengers (Padayatty et al. 2003).
- Delphinidin is an anthocyanin compound present mainly in purple-coloured peppers is a major source for UV protection and antioxidants.
- Peppers are rich sources of α- and β-carotene and β-cryptoxanthin, which are main carotenoids contributing to provitamin A activity (IOM 2001).
- Red peppers are the richest source of α-carotene, whereas yellow and orange chillies are for β-cryptoxanthin.
- Antioxidant properties of chilli fruits, mainly ascorbic acid (vit C), reach levels up to fivefold higher than the necessary daily intake needed for human consumption (FDA) (Mohd Hassan et al. 2019; Mendes and de Andrade Gonçalves 2020).

14.3.3.1 Capsaicinoids

Capsaicinoids are amides produced by *Capsicum* species. These secondary metabolites are responsible for the strong and hot taste of the fruits, also known as pungency. Capsaicinoids consist of compounds that differ in the structure of branched fatty acid (acyl) moieties attached to the benzene ring of vanillylamine. Capsaicin and dihydrocapsaicin are the two major capsaicinoids found in hot peppers (more than 90% of the total capsaicinoids). Levels of total capsaicinoids can be converted to Scoville Heat Units (SHU), a measurement for pungency developed by Wilbur Scoville. One part per million (ppm) of capsaicin has a pungency of 15 SHU. Scoville categorized four pungency groups: mild (0–5000 SHU), medium (5000–20,000 SHU), hot (20,000–70,000 SHU) and extremely hot (70,000–300,000).

Properties of capsaicin—Highly volatile with a pungent odour, pure capsaicin is a hydrophobic and colourless crystalline to waxy substance. **Action mechanism of capsaicinoids**—Pungency in chilli is due to the activation of TRPV1(VR1) receptor. In fact, the TRPV1 receptor is involved in several pain-sensing pathways, which has prompted much basic and clinical research on the use of capsaicinoids. **Site of synthesis**—Chilli starts accumulating capsaicinoid in fruits approximately 20 days post-anthesis. The biosynthesis of this compound occurs in the epidermis cells of the placenta and dissepiment tissues of the *Capsicum* fruit. These compounds are transported out of the epidermal cells and stored in the vesicles of the placenta, also called 'blisters'. Seeds do not produce capsaicin but can draw capsaicin from the surrounding tissue. Capsaicinoids not only are present in the fruits but can also be found in vegetative organs such as the leaves and stems, although at a much lower concentration than found in the fruits.

14.3.3.2 Capsinoids

Capsinoids are low-pungent capsaicinoid analogues, which were first isolated from a low-pungent *Capsicum annuum* cultivar, 'CH-19 Sweet'. They are similar in structure to capsaicinoids but have an ester group instead of an amide group. The major capsinoids in nature are capsiate, dihydrocapsiate and nordihydrocapsiate. Capsinoids have similar medicinal values and considerably lower pungency than capsaicinoids. Low pungency of capsiate makes it more palatable. Capsinoids are unstable and easily degraded in the aqueous phase. Capsinoid has advantage over capsaicinoid in biomedical uses and is more favourable as ingredients in dietary foods and supplements than capsaicinoids.

Both capsaicinoids and capsinoids exhibit a wide range of medicinal values, such as the suppression of fat accumulation and anti-inflammatory, antioxidative and anti-cancer effects (Aza-González et al. 2011; Luo et al. 2011). Self-protection aerosol sprays using capsaicinoids as the main active ingredient are currently in the market (Fung et al. 1982; Andrews 1995; Reilly et al. 2001). Capsaicinoids have antimicrobial properties; for example, Tewksbury et al. (2008) described that these substances are capable of inhibiting the growth of *Fusarium* fungus, which is a major problem in post-harvest fruits and vegetables. Consequently, capsaicinoids might be useful as biopesticides.

14.3.3.3 Carotenoids

Carotenoids are increasingly drawing the attention of researchers as a major natural food colour due to their inherent nutritional characteristics and the implicated possible role in prevention and protection against degenerative diseases. Red pepper pods are abundant with diverse carotenoids, and their composition largely depends on the varieties and geo-climatic conditions of cultivation. Capsanthin contributes 30–70% of carotenoids in most of the varieties and cultivars. The proportions of capsanthin and capsorubin increase in the advanced stages of ripening. The capsanthin-capsorubin synthase gene is a candidate gene for the *y* locus controlling the red fruit colour in pepper (Lefebvre et al. 1998). There is a relationship between red fruit colour formation and key genes of capsanthin biosynthesis pathway in *Capsicum annuum* (Tian et al. 2015).

14.3.3.4 Oleoresins

Capsicum oleoresin is a concentrated extract from chilli fruits and is an oily red mixture that contains capsaicinoids and colourants.

Why oleoresins? Achieving efficient and consistent results using ground spices is a challenging task. Oleoresins can replace the original ground spice with a standardized taste and aroma that can be tailored as per the requirement of the product. They are economical, with easier quality control, and require lesser storage space. They have a longer shelf life, are cleaner (no bacterial contamination) and are a convenient substitute for ground spices.

Paprika oleoresin (capsanthin, capsorubin) Paprika is manufactured from the dried and ground sweet pepper pods of ***Capsicum annuum***. The colourings that impart the characteristic yellow to orange hue of paprika are ***capsanthin*** and ***capsorubin***. Paprika, a red spice, imparts flavour and colour to food. Paprika, the ground, dried fruit of *Capsicum annuum*, has been used as a colour and/or spice for centuries as the raw ground powder. Paprika colour compounds can also be solvent extracted to produce paprika oleoresin, a purified form of the colouring compounds.

14.3.4 Chilli Is Rich in Other Bioactive Compounds

Chilli fruits are a very rich source of health-promoting bioactive compounds such as carotenoids (lutein, capsanthin, capsorubin, zeaxanthin, violaxanthin, etc.), ascorbic acid, tocopherols and capsaicinoids. Many of these compounds are antioxidants and free radical scavengers (Padayatty et al. 2003). Anthicynindelhinidin compound present mainly in purple-coloured peppers is a major source for UV protection and antioxidants. Peppers are rich sources of α- and β-carotene and β-cryptoxanthin, which are main carotenoids contributing to provitamin A activity (IOM 2001). Red peppers are the richest source of α-carotene, whereas yellow and orange chillies are for β-cryptoxanthin. Antioxidant properties of chilli fruits, mainly ascorbic acid (vit C), reach levels up to fivefold higher than the necessary daily intake needed for human consumption (FDA) (Mohd Hassan et al. 2019; Mendes and de Andrade Gonçalves 2020). Due to the emerging eco-friendly adoption of consumers and industries, there is a spike in exploring bioactive compounds and plant extracts as natural ingredients for food, cosmetic and pharmaceutical use. There are various cases of chilli oleoresin used as cosmetic colourants in bath oils, shampoo, shower gels and beauty products such as lipsticks (Baenas et al. 2019). The bioactive compounds extracted from pepper by-products can also be utilized as flavouring or fragrance agents in cosmetic products without any toxic side effect (Johnson 2007).

14.3.5 Metabolite Biodiversity in Pepper

Wahyuni et al. (2011) performed a comprehensive study on the morphology and biochemical compounds of 32 *Capsicum* sp. accessions. Major metabolites identified in fruits were carotenoids, capsaicinoids (pungency), flavonoid glycosides and vitamins C and E and were quantified by high-performance liquid chromatography. Levels of both O- and C-glycosides of quercetin, luteolin and apigenin varied strongly between accessions. Capsaicinoid levels ranged from 0.07 up to 80 mg/100 g fruit wt. in fruit pericarp; vitamin C levels were detected up to 200 mg/100 g fruit wt. and vitamin E concentration up to 16 mg/100 g fruit wt. The metabolite analysis showed that chilli fruits are a very good source of three major vitamins (A, C and E). Vit C levels in chilli were found to be tenfold higher than in tomato. The level of α-tocopherol (vitamin E) was found to be high in the accession of *C. chinense* AC2212 (No. 24), which is moderately high compared to other edible plants. An overview of the metabolic diversity in ripe fruits of a collection of 32 diverse pepper (*Capsicum* sp.) accessions was obtained by measuring the composition of both semi-polar and volatile metabolites in fruit pericarp, using untargeted LC-MS and headspace GC-MS platforms, respectively (Wahyuni et al. 2013). Accessions represented *C. annuum*, *C. chinense*, *C. frutescens* and *C. baccatum* species, which were selected based on variation in morphological characters, pungency and geographic origin. Genotypic analysis using AFLP markers confirmed the phylogenetic clustering of accessions according to *Capsicum* species and separated *C. baccatum* from the *C. annuum–C. chinense–C. frutescens* complex. Species-specific clustering was also observed when accessions were grouped based on their semi-polar metabolite profiles. In total, 88 semi-polar metabolites could be putatively identified. A large proportion of these metabolites represented conjugates of the main pepper flavonoids (quercetin, apigenin and luteolin) decorated with different sugar groups at different positions along the aglycone. In addition, a large group of acyclic diterpenoid glycosides, called capsianosides, was found to be highly abundant in all *C. annuum* genotypes. In contrast to the variation in semi-polar metabolites, the variation in volatiles corresponded well to the differences in pungency between the accessions. This was particularly true for branched fatty acid esters present in pungent accessions, which may reflect the activity through the acyl branch of the metabolic pathway leading to capsaicinoids. In addition, large genetic variation was observed for many well-established pepper aroma compounds. These profiling data can be used in breeding programmes aimed at improving metabolite-based quality traits such as flavour and health-related metabolites in pepper fruits (Wahyuni et al. 2013).

14.4 Capsicums for Entrepreneurship

14.4.1 Capsicums in Farming Business

Good agricultural practices for capsicum's cultivation include climate and soils, selection of a variety, procurement of quality seeds, seed rate and seed treatment [*Trichoderma viride* @ 4 g/kg or *Pseudomonas fluorescens* @ 10 g/kg], sowing/planting season, nursery management, integrated nutrient management, weed management, crop management, integrated pest and disease management and harvest and post-harvest management.

Integrated pest and disease management involves growing of nursery under nylon net cover (40–60) mesh, seedling raising on microbial enriched FYM and neem cake in the nursery bed or portrays, growing border crop with two rows of maize/jowar, mulching with silver or white polythene agri-mulch sheet, use of yellow and blue colour sticky traps 40 per acre, selective application of pesticides/oils/botanicals/microbial formulations at 7–10-day interval 15 days after transplanting until fruit formation, growing of virus-resistant hybrids/varieties and avoiding the use of unlabelled biopesticides and tonics.

14.4.2 Capsicums in Seed Business

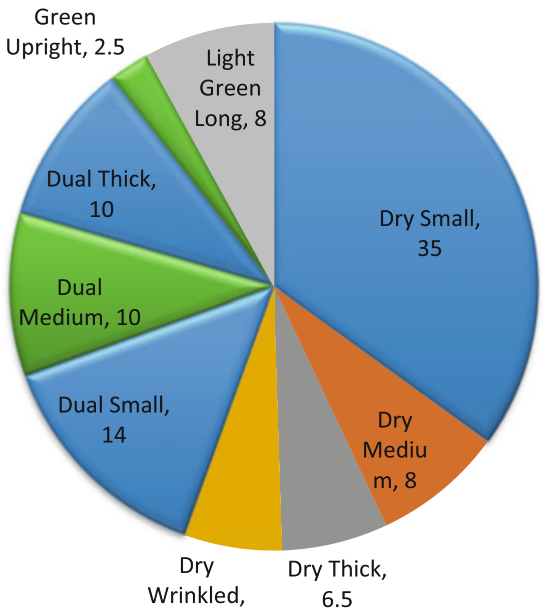
Chilli OP and F1 seed demand in India: F_1 seed demand/year—100 t; OP seed demand/year—50 t; seed value/year—350 crores.

OP seed production—Growing inbred lines in isolation or in nets to avoid out-crossing.

F_1 hybrid seed production: Steps involved are emasculation, pollination and seed extraction:

- Tedious due to small flower size
- No. of seeds/act of pollination low

Use of GMS/CGMS system in hybrid seed production in chilli is commercially exploited.



Segment-wise market share of chilli in India

14.4.3 Capsicums in Seedling Business

- Open conditions (flat/raised beds)
- Screen house
- Grafting

Seed rate: OP variety—100–120 g/acre and F_1 hybrid—60–70 g/acre

Use protrays filled with sterilized cocopeat; insect-proof net of 5 m × 4.5 m × 2 m size accommodates 100–120 protrays (98 cells) and ~10,000–12,000 seedlings sufficient for an acre.

Nursery techniques Raise nursery in well-tilled soil by making beds 0.8–1.0 m wide and 15 cm high. Add 5 kg of enriched FYM, 0.5 kg of neem cake and 100 g of 15:15:15 complex fertilizer along with 2.5 g carbofuran per m^2. Drench beds with Captan (2 g/L) or copper oxychloride (4 g/L). Sow seeds thinly in rows 10 cm apart and 0.5 cm deep. Cover beds thinly with compost before mulching with dry straw or grass and drench with Captan or copper oxychloride. After the appearance of first true leaf, seedlings are thinned out. On the 20th day monocrotophos (1.5 mL/L) and on the 25th day zineb (2 g/L) are sprayed. During the last week in the nursery, the seedlings may be hardened by slightly withholding water.

14.4.3.1 Solarization of Nursery Bed

- It is a nonchemical method of nursery bed sterilization.
- Prepare the bed, and irrigate to bring to field capacity.
- Cover with 200-gauge clear polyethylene sheet tightly over the soil bed.
- Leave for 30 days.
- After removing the cover, sow without disturbing the soil.

14.4.3.2 Advantages of Protray Seedling Production

- Right media—good germination
- Each seedling—equal area—uniform growth
- Seedling mortality, better controlled
- Less loss of expensive seed
- Transplant establishment, crop stand better
- Uniform and early maturity
- Reduced viral disease damage

14.4.3.3 Protected Structures

- Nylon net house is popular
- 40 mesh nylon net, 35% shade net, granite pillars, GI wire
- Polyhouse, low-cost wooden polyhouse
- Low-tunnel structure—in case of net house
- Plastic mulched raised bed to keep the trays

Grafting technique in *Capsicum* Very recently, grafting technique has been exploited to overcome soil-borne diseases.

14.4.4 Capsicums in Export Business

Chilli in dry form is one of the topmost foreign exchange earners of spices and has earned Rs. 6221.7 crores (Spice Board 2019–2020). The crop is being exported in varied forms like

- Green chilli
- Dry chilli (whole pods/flakes/powder)

- Oleoresins
- Chilli seed oil
- Quality seeds

14.4.5 Capsicums in Food Industry

Capsanthin is being used in the agro-food and cosmetic industry as a natural colorant. Due to the emerging eco-friendly adoption of consumers and industries, there is a spike in exploring bioactive compounds and plant extracts as natural ingredients for cosmetic use. **Carotenoids** as natural pigments are used by the **industry** as pharmaceuticals, nutraceuticals and animal feed additives, as well as colourants in cosmetics and special **foods**. There are various cases of chilli oleoresin used as cosmetic colourants in bath oils, shampoo, shower gels and beauty products such as lipsticks (Baenas et al. 2019). The bioactive compounds extracted from pepper by-products can also be utilized as flavouring or fragrance agents in cosmetic products without any toxic side effect (Johnson 2007).

Carotenoids The diverse and brilliant colours of pepper fruit originate from the carotenoid pigments present in the thylakoid membranes of the chromoplasts; the most common carotenoid pigments found in peppers are **yellow food colouring agents—**antheraxanthin, β-carotene, β-cryptoxanthin, lutein, violaxanthin and zeaxanthin—and **orange-red food colouring agents**—capsanthin, capsorubin and cryptocapsin.

14.4.6 Capsicums in Pharmaceutical Industry

Chilli seed essential oil is used to stimulate **hair growth** and reduce hair loss. It is good for the heart and a source of protein, with benefits of **iron** and vitamins C, A, E, D and K. Chillies help with reducing heart diseases because it contains a high level of potassium. The elements itself help with easy blood flow throughout your body. So, each time you consume chillies, the heat rush sensation you feel is your airways receiving oxygen.

Oleoresins are semi-solid extracts composed of resin and essential or fatty **oil**, obtained by . . . ginger, jambu, labdanum, mace, marjoram, nutmeg, parsley, **pepper** (black/white), pimenta (allspice), rosemary, sage, ... **Oleoresins are similar** to perfumery concretes, obtained especially from flowers, and to perfumery resinoids, ...

Zeaxanthin is an **eye** vitamin that, once inside the body, is drawn to the eyes. It makes its way into the lens, macula and fovea (the centre spot of the retina). Zeaxanthin helps build a yellow-coloured pigment shield to protect the **eye** cells from the harmful effects of certain light sources, such as the sun. It also protects the eyes from dangerous free radicals that form over time from oxidation. Zeaxanthin, along with lutein, is the only dietary carotenoid that accumulates in the retina, particularly the macular region. (Meso-zeaxanthin is the third dominant carotenoid at the very centre of the macula, where zeaxanthin is dominant just off-centre.) Because both substances are found in large amounts in the macula, they are known as macular pigments. Orange pepper was the vegetable with the highest amount of zeaxanthin (37% of total).

14.4.7 Capsicums in Defence

- **Unique defence mechanism**—Capsaicinoids are also an active ingredient in riot control and personal defence pepper spray agents. When the spray comes in contact with skin, especially eyes or mucous membranes, it produces pain and breathing difficulty in the targeted individual.
- Capsaicin is also used to deter pests, specifically mammalian pests. Targets of capsaicin repellents include voles, deer, rabbits, squirrels, bears, insects and attacking dogs. Ground or crushed dried chilli pods may be used in birdseed to deter rodents, taking advantage of the insensitivity of birds to capsaicin.
- The Elephant Pepper Development Trust claims that using chilli peppers as a barrier crop can be a sustainable means for rural African farmers to deter elephants from eating their crops.
- Although hot chilli pepper extract is commonly used as a component of household and garden insect-repellent formulas, it is not clear that the capsaicinoid elements of the extract are responsible for its repellency.
- The first pesticide product using solely capsaicin as the active ingredient was registered with the U.S. Department of Agriculture in 1962.
- **Equestrian sports**—Capsaicin is a banned substance in equestrian sports because of its hypersensitizing and pain-relieving properties. At the jumping events of the 2008 Summer Olympics, four horses tested positive for the substance, which resulted in disqualification.

14.4.8 Capsicums for Solar Cells

- Ultra-thin solar cells made with **lead-based materials** can absorb light more efficiently than silicon-based solar cells, but they often cannot convert energy as efficiently because they lose some of it to heat.
- Scientists added capsaicin extracted from chillies to these ultra-thin solar cells during the manufacturing process. Capsaicin made the solar cells more efficient, yielding a power conversion of 21.88%, versus 19.1% without capsaicin.
- The team then analysed the solar cells with spectroscopy while conducting energy and found that the addition of capsaicin did indeed lead to a greater number of free electrons available to conduct current at the solar cells' surface. This reduced energy leakage via heat.
- The exact mechanism behind this improvement is being investigated.

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15 Genetic Resources of Vegetable Crops: A Potential Source of Nutrition and Entrepreneurship in North-Eastern Region of India

Veerendra Kumar Verma, Heiplanmi Rymbai, and Pankaj Baiswar

Abstract

North-eastern region of India is a part of Indo-Myanmar region of biodiversity hotspot of the world and known for its diverse agro-climate and is also the centre of diversity of numerous conventional and non-conventional vegetable crops. Moreover, majority of the population of the region, especially children and women, suffer from protein energy malnutrition and disorders related to micronutrient (vitamins and minerals), which is essential for sustaining life and physical activities. The major factor for the above-mentioned problems is the use of only few crops in the diet such as potato, cabbage, tomato, cauliflower and brinjal as they are contributing to over 64% of the total production. These problems can be dealt through sensitization about the nutritional value of the potential vegetable crops and diet diversification with nutritionally superior crops like beans (Indian bean, broad bean, winged bean, lima bean, velvet bean, tree bean), cucurbits (chow-chow, teasel gourd), solanaceous crops (bird's-eye chilli, dalle, chillies, king chillies, tree tomato), cole crops (cabbage, cauliflower and broccoli), *Moringa oleifera*, leafy vegetables (*Brassica juncea*, *Basella alba*, *Malva verticillata*, *Amaranthus* spp., *Allium* spp.), ferns (*Diplazium esculentum* (Retz.) Sw., *Huperzia phlegmaria* (L.) Rothm., *Huperzia squarrosa* (G. Forst.) Trevis. and *Nephrolepis cordifolia* (L.) C. Presl), bamboo shoots (*Bambusa balcooa*, *Bambusa pallida, Dendrocalamus* spp. and *Melocanna baccifera*), aromatic crops (*Ocimum* spp., *Eryngium foetidum*, *Murraya koenigii*, *Zanthoxylum* spp.), tuber crops (tapioca, yam, sweet potato and colocasia) and other perennial fruits like jackfruit (*Artocarpus heterophyllus*), which are well suited for the region. Further, livelihood security of the marginal and small farmers can also be ensured by the production of high-value crops like king chillies, bird's-eye chillies,

V. K. Verma (✉) · H. Rymbai · P. Baiswar
ICAR Research Complex for North Eastern Hill Region, Umiam, Meghalaya, India

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capsicum and mushrooms under protected conditions. The diverse genetic resources with unique desirable traits could be utilized for further improvement. Moreover, there is a need to assess the nutraceutical properties of the diverse potential crops of the region and focus on the conservation of the genetic resources in situ under field gene bank in ecological niche areas and also under ex situ conditions.

Keywords

Biodiversity · Vegetable crops · North-eastern region · Nutritional values · Livelihood security

15.1 Introduction

The north-eastern region of India, comprising the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, lies between 21.5°N to 29.5°N latitude and 85.5°E to 97.5°E longitude. The region is characterized by diverse climate regimes ranging from subtropical to alpine; and comes under high-rainfall zone, which is dependent mainly on the southwest monsoon (June–September), and drainage is through two main river basins (the Brahmaputra and Barak). The region is also characterized by diverse terrain, wide variations in slopes, altitude, land tenure systems and diverse cultivation practices.

Due to diverse climate, the region is a hotspot of biodiversity, and a wide range of wild and cultivated species are grown in the region. The Indian subcontinent represents one of the richest diverse genetic resources. Of the estimated 250,000 species of flowering plants at a global level, about 3000 are regarded as food source, in which only 200 species have been domesticated. Global diversity in vegetable crops is estimated at about 400 species, with about 80 species of major and minor vegetables reported to have originated in India (Chadha 2009). Diverse agro-climatic conditions of India are suitable for growing more than 60 cultivated and about 30 lesser known vegetable crops. Besides, there are numerous underutilized and non-conventional cultivated and wild vegetables used traditionally by the different tribes of the region. Commercial cultivation of few crops has resulted in the marginalization of a large group of locally important crops, which were otherwise appreciated by communities because of their adaptability to marginal farming conditions, relevance to local food culture and diverse nutritional values and nutraceutical advantages. These crops belonging to categories such as cereals and pseudo-cereals, legumes, vegetables, oilseeds, roots and tubers, aromatic and medicinal plants, and fruits and nuts have earned collective names such as 'neglected and underutilized' or 'forgotten', 'orphan' and 'minor' crops (Padulosi and Hoeschle-Zeledon 2004, 2008).

The term underutilized species refers to the category of wild and cultivated species whose potential has not been fully realized. It may also refer to local varieties of major crops and commodities currently abandoned by farmers or in decline but which could be revived through specific interventions such as adding value or marketing (Padulosi and Hoeschle-Zeledon 2004). Jaenicke and Höschle-Zeledon (2006) have defined underutilized species as "species with under-exploited potential for contribution to food security, health (nutritional/medicinal), income generation and environmental services" (Table 15.1).

The underutilization of crop species is due to several factors such as lack of competitiveness in terms of yield, quality, adaptability, storability, poor demand due to consumer preferences and socio-economic factor.

The underutilized species are characterized by the following features:

- Importance in local consumption and production systems
- Highly adapted to agro-ecological niches and marginal areas
- Ignored by policymakers and excluded from research and development agendas
- Represented by ecotypes or landraces—they require improvement
- Cultivated and utilized drawing on indigenous knowledge; urbanization and changing farming methods are contributing to the rapid erosion of traditional knowledge
- Hardly represented in ex situ gene banks, maintained by a 'conservation through use approach'
- Characterized by fragile or non-existent seed supply systems

Vegetable crops are known as protective foods as they are a rich source of micronutrients (vitamins, minerals and secondary metabolites). According to the Recommended Dietary Allowances (RDA) of the Indian Council of Medical Research (ICMR), the per capita consumption of vegetables must be 300 g, and at present, the per capita availability of vegetables is ≈400 g, which is about 25% higher over the RDA. However, they are lacking in balanced nutrition as over 64% of the total production share is contributed by only five crops such as potato (20.4%) followed by cabbage (18.17%), tomato (9.56%), cauliflower (9.28%) and brinjal (6.88%). Therefore, to ensure the nutritional security, it is imperative to promote diversification of diets through promotion of nutritionally superior vegetable crops. According to the World Health Organization, protein energy malnutrition (PEM) refers to 'an imbalance between the supply of protein and energy and the body's demand for them to ensure optimal growth and function' (Onis et al. 2000). It is a major public health problem in India. In Arunachal Pradesh, approximately 29.3% (stunting, wasting, undernutrition) under age 3 suffer from protein energy malnutrition (Pandey et al. 2014). It affects particularly the preschool children (<6 years) with its dire consequences ranging from physical to cognitive growth and susceptibility to infection. This affects the child at the most crucial period of time of development, which can lead to permanent impairment in later life (Park 2007). As rice is the main source of carbohydrates in the region, the addition of tuber crops with legume vegetables in diet may be helpful in solving the problems of PEM. Besides, over 40% of population of the region suffers from anaemia. In Meghalaya, 47.2% of women suffer from anaemia and 64.4% of children suffer from malnutrition. To overcome the problems of micronutrient deficiency disorders, diet

Table 15.1 List of important underutilized species of vegetables grown in north-eastern states of India

Common name	Species	Uses	Distribution
1. Solanaceae			
Bitter tomato	*Solanum gilo*	Fruits for cooking and chutney	Entire NE states of India
Pea eggplant	*Solanum torvum*	Fruits for cooking	
African eggplant	*S. macrocarpon*	Leaves and fruits for cooking and chutney	
Badi kateri	*S. indicum*	Fruits for cooking and chutney	
Dalle chilli	*Capsicum annuum*	Fruits as pickles	Sikkim
Bird's-eye chilli	*C. frutescens*	Fruits for pickles, cooking	Entire NE states
King chilli	*C. chinense*	Fresh fruits, pickling, etc.	Upper Assam, Nagaland, Manipur, Mizoram
–	*C. pubescens*	Pickling of fruits	–
Tree tomato	*Cyphomandra betacea* Sendt.	Fruits for cooking and chutney	Entire NE states
2. Cucurbitaceae			
Chow-chow	*Sechium edule*	Leaves, fruits and roots for cooking	NEH region, Southern Hills
Teasel gourd	*Momordica subangulata* subsp. *renigera*	Fruits for cooking	Entire north-eastern states
Ucche	*Momordica charantia* L. var. *muricata*	Fruits for cooking	Assam, Tripura, West Bengal
Achocha, Caygua	*Cyclanthera pedata*	Fruits for cooking	Meghalaya
Fig leaf gourd	*Cucurbita ficifolia*	Fruits for cooking	Meghalaya
African horned melon	*Cucumis metuliferus*	Fruits as salad	Sikkim
Snake gourd	*T. cucumerina* var. *anguina*	Fruits for cooking	Meghalaya, Tripura and Assam
3. Brassicaceae			
Mustard green	*Brassica juncea* var. *rugosa*	Leafy vegetable	Entire NE states

(continued)

Table 15.1 (continued)

Common name	Species	Uses	Distribution
4. Malvaceae			
Laffa	*Malva verticillata*	Leafy vegetable	Some parts of the region
Rosella	*Hibiscus sabdariffa*	Flower and leaf for cooking and chutney	Some parts of the region
5. Leguminosae			
Broad bean	*Vicia faba*	Seeds as vegetable and dal	Manipur, Mizoram, Tripura
Lima bean	*Phaseolus lunatus*	Seeds as vegetable	Entire NE India
Winged bean	*Psophocarpus tetragonolobus*	Pods for cooking	Entire NE India
Jack bean	*Canavalia ensiformis*	Pod for cooking	Manipur, Mizoram, Nagaland, Meghalaya
Wild sweet pea	*Vigna vexillata*	Edible tubers	Tripura
Sohphlang	*Flemingia vestita*	Peeled tubers for fresh consumption	Meghalaya
Tree bean	*Parkia roxburghii*	Pods for cooking	Entire NE states of India
6. Alliaceae			
Chollng	*A. chinense*	Green leafy vegetable	Meghalaya, Manipur, Nagaland, Mizoram, Arunachala Pradesh
Maroi napakpi	*Allium hookeri*	Green leafy vegetable and soup	
Other species	*A. tuberosum, A. fistulosum, A. ascalonicum, A. macranthum, A. prattii, A. rubellum, A. wallichii*	Green leafy vegetable	
7. Basellaceae			
Poi	*Basella alba*	Leafy vegetables	Assam, Tripura
Spanish coriander	*Eryngium foetidum*	Leafy vegetable for aroma	Entire NE states
8. Amaranthaceae			
Amaranth	*Amaranthus* spp.	Leafy vegetable	Entire NE states
9. Chenopodiaceae			
Bathua	*Chenopodium album L.*	Leafy vegetable	Entire NE states
10. Polygonaceae			
Kangany/ Machan-pilu	*Persicaria nepalensis/Polygonum alatum*	Leafy vegetable	Entire NE states
Buck wheat	*Fagopurum cymosum*	Leafy vegetable	

(continued)

Table 15.1 (continued)

Common name	Species	Uses	Distribution
Sorrel	*Rumex* spp.	Leafy vegetable	
11. Rutaceae			
Curry leaves	*Murraya koenigii*	Leaf for cooking, curry and other products	Entire NE states
Jaiur (Khasi)	*Zanthoxylum* spp.	Aromatic leaves for flavour	
12. Zingiberaceae			
Mango ginger	*Curcuma amada*	Rhizome for pickling	Parts of NE states of India
Black turmeric	*Curcuma caesia*	Rhizome for pickling	
Aromatic ginger	*Kaempferia galanga*	Rhizome for cooking vegetables/meat for aroma	
Black ginger	*Kaempferia parviflora*	Rhizome for cooking vegetables/meat for aroma	
13. Saururaceae			
Heart leaf/ Masundari	*Houttuynia cordata* Thunb.	Leaf for cooking and salad purpose	Entire NE states
14. Portulacaceae			
Water leaf/Pirali Paleng	*Talinum triangulare* (Jacq.) Willd.	Leafy vegetable	Parts of NE states
Purslane/ Malbhog khutora	*Portulaca oleracea L*	Leafy vegetable	Parts of NE region
15. Araceae			
Tania	*Xanthosoma sagittifolium*	Leaf and petiole	Entire NE region
Swamp taro	*Cyrtosperma merkusii*	Tubers as vegetable	Entire NE region
16. Dioscoreaceae			
Yam	*Dioscorea* spp.	Tubers for cooking	Entire NE region
17. Moraceae			
Jackfruit	*Artocarpus heterophyllus*	Tender fruits for vegetable	Entire NE region

Source: Asati et al. (2004); Hore et al. (2007); Deka et al. (2012)

diversification with nutritionally superior vegetables including underutilized and leafy vegetables may be useful.

The region being a biodiversity hotspot, there is wider diversity in different nutritionally superior conventional and non-conventional vegetable crops as described below:

15.1.1 Legume Vegetables

The region is rich in genetic resources of many seasonal (Indian bean, cowpea, French bean, lima bean, broad bean, winged bean, jack bean, etc.) as well as perennial (tree bean) legume vegetables. Legume vegetables are an important source of protein, carbohydrates, vitamins and minerals.

French bean: It is grown in most parts of north-eastern states. Crop is available almost round the year in market. There are two main growing seasons, i.e. February–March for the tender pods and July–August for the pod as well as seed purposes. Climbing or pole type is popular among the tribal population since it is used for mix cropping with maize, the stem of which acts as the support for the bean. Wider genetic diversity has been observed with respect to seed and pod size and colour as well as plant height. The crop is a rich source of crude fibre, and it ranges from 12.66 to 34.17%. Quantitative traits such as yield, pod weight, number of pods per plant and number of seeds per pod contribute to 62.26% of genetic diversity in the region (Verma et al. 2014).Under AICRP on vegetable crops, ICAR Research Complex for NEH Region, Umiam, Meghalaya, 94 germplasms (73 pole type and 21 bush type) from different parts of the north-eastern India were collected and evaluated. Among the pole type, the highest yield per plant was recorded from the genotypes MZFB-47 (320 g), MZFB-45 (302 g), RCFB-88 (266 g), RCFB-34 (252 g), MZFB-36 (251 g) and RCMFB-1A (250 g) compared to Naga Local (166 g). However, in bush type, the highest yield was recorded from the RCFB-3 (133 g) compared to Arka Anoop (62 g). The seed weight ranged from 22 g (RCFB-5) to 60 g (Nagal Collection-1). High-yielding anthocyanin-rich purple genotypes MZFB-45 (315.25 g) and MZFB-48 (290 g/plant) were found to be field tolerant to moisture stress.

Pea (*Pisum sativum*): Garden pea is an important source of protein (7.2%) in the region. It is also rich in crude fibre (5%), vitamins and minerals. The crop is grown during October–February. Besides local landraces, popular varieties grown in the region are Arkel, Azad Pea-1, Azad Pea-4 and Prakash, TSX-10. Field pea is mostly grown in Assam, Manipur and Tripura, and the popular cultivar is Rachna. The green pod yield ranges from 87 to 105 Q/ha (cv. TSX-10) under the mid-hills of Sikkim (Lepcha et al. 2015). In mid-hills, pea is grown under zero tillage after harvesting of rice. Pea is grown under rice-pea and maize-pea cropping sequence. It is also cultivated in intercropping with other vegetable crops like mustard, cabbage and cauliflower.

Indian bean (*Lablab purpureus*): This crop is the third most widely grown leguminous vegetable crop after pea and French bean. It is grown in almost all the north-eastern states of India during July–March. Being the centre of origin, wider genetic diversity has been observed in the region with respect to flower, pod and seed colour, pod and seed size, etc. The crop is grown for tender pod and mature seed purpose. The tender pods are rich in protein (3.6%) and fibre (1.8%). However, dry seed contains 23.0–28.0% of protein. ICAR Research Complex for NEH region maintains 165 accessions of Indian bean, and wider variability in yield and quality traits has been recorded. The pod weight ranges from 4.80 to 21.36 g, no. of seeds per pod 3.0 to 8.0, yield per plant 257.0 to 2685 g, protein content 15.57 to 36.75 mg/100 g, vitamin C 20.16 to 51.84 mg/100 g and anthocyanin content 0.12 to 10.45 mg/100 g. Among the accessions, high-yielding genotypes were ASDBC-16 (2.68 kg/plant) followed by TRDBC-11 (2.02 kg) and TRDBC-16 (1.77 kg). Some unique genotypes were identified as TRDBC-9 (21.30 cm) for high pod length; Selection-1 was identified as high-yielding (326 g), photo-insensitive bush-type line of Indian bean. The anthocyanin rich lines are MZDBC-25 (10.45 mg/100 g), MNDBC-11 (10.43 mg/100 g) and MNDBC-6 (7.68 mg/100 g). Rai et al. (2014) observed significant genotypic variation in the level of protein (102–635.6 mg/g), sugar (0.188–1.11 mg/g), chlorophyll (0.121–0.716 mg), phenol (1.7–9.67 mg/g), proline (0.02–7.06 μg/g) and carotenoid (0.04–0.231 mg/g) content in Dolichos bean. In north-eastern India, it is commercially grown as Dolichos bean (August–March)-cucurbits (bottle gourd/bitter gourd/cucumber/sweet gourd during March–August) cropping sequence, especially in Tripura, Barak and Brahmaputra valleys.

Cowpea (*Vigna unguiculata*): Cowpea is the third most important legume vegetable crop of the region. It is also sown twice a year during March–April and August–September. The popular cultivars are Kashi Kanchan (bush type) and Pusa Komal (pole type). Wide range of variability has also been observed in this crop for seed colour (white, cream, brown and black), and pod length ranged from 15.5 cm (RCCP-11) to 40 cm (RCCP-8). Under vegetable-based cropping sequence, chilli-cowpea-radish were found most suitable for the raised bed in lowland area.

Broad bean (*Vicia faba*): It is grown as a dual-purpose crop: tender pods as vegetable and mature seeds for dal purpose. It is cultivated in almost entire north-eastern states during winter season (October–March). Faba beans contain a large amount of proteins, carbohydrates, B-group vitamins and minerals. The protein content of faba beans ranges from 20 to 41%, values which depend on the variety (Chavan et al. 1989). Faba bean seeds contain 51–68% of carbohydrate in total, the major proportion of which is constituted by starch (41–53%) (Cerning et al. 1975). Faba beans are a good source of dietary minerals, such as phosphorus, potassium, calcium, sulphur and iron. Calcium content ranges from 120 to 260 mg/100 g dry mass (Chavan et al. 1989). It is a nitrogen-fixing plant and is not poisonous to humans in the conventional sense, but they cause favism in susceptible individuals, who have a genetically transmitted, male sex-linked deficiency to the enzyme glucose-6-phosphate dehydrogenase. The disease can cause death in severe cases.

Rice bean (*Vigna umbellata*): It is a hardy leguminous crop cultivated in the north-eastern states of India for its tender pods and seeds. It is found in wild form in natural habitats like the Khasi and Jaintia Hills of Meghalaya. One of the interesting species of *Vigna*, namely *V. vexillata*, is grown by the tribals of Tripura. It is a legume-cum-tuber crop with much variation in edible tubers (Arora and Pandey

1996). Thirty landraces of the legume *Vigna umbellata*, collected from the hilly state of Nagaland, Northeast India, were screened for nutritive value by the Department of Biotechnology, Guwahati University, Guwahati, and it was found that crude protein content varied from 14.66 to 26.88%.

Sword/jack bean (*Canavalia ensiformis* (L) DC): Sword bean of Papilionaceae family is cultivated on limited scale in the north-eastern region (CSIR 1950). It is a bushy, semi-erect, annual herb, 2 m tall, and the tips of its branches tend to twine under shade. Leaves are trifoliate and shortly hairy. Pods are sword shaped, 2–30 cm long and 2–2.5 cm broad. The pods are pendent, ribbed near suture and 8–20 seeded. Seeds are white with a brownish hilum extending to half of its length. Young green pods are eaten as a cooked vegetable. The young leaves may be cooked and eaten as a potherb. It is also grown for the fodder purpose. The dried beans are a good source of protein and starch (27% protein and 42% starch, respectively) with a good balance of amino acids and some toxic alkaloids of non-protein-nitrogen compounds like lectins, canavanine, concanavalin and canaline, which are heat labile and hydrosoluble. The lectin reacts with the sugar components in intestinal cells causing a disruption in cell structure, which leads to abnormalities in nutrient absorption (D'Mello et al. 1985). However, the canavanine is a major toxic factor, which is present to an extent of 2.0–3.5% of dry seed (Fearon and Bell 1955), which also inhibits protein metabolism.

Winged bean (*Psophocarpus tetragonolobus*): It is a creeping-type plant and is mostly grown in home garden, particularly in South India and Northeast India. Winged bean is confined in humid subtropical parts of NE region (Sarma 2001). It is grown in the home gardens in Assam, Tripura and Meghalaya. Winged bean is nutrient rich, and all parts of the plant are edible. Leaves can be eaten like spinach, flowers can be used in salads, tubers can be eaten raw or cooked and seeds can be used in similar ways as the soybean (Khan 1982). It is grown in pits and needs organic manure and fertilizers like other beans. To trail the branches, it needs a bower or trellis. It grows vigorously, and flowering starts within 3 months. A robust, climbing herbaceous perennial plant, it can attain 5 m in height. The flowers are of different colours; it may be blue, white or purple. The pods are four sided with characteristic wings and vary in length from 6 to 36 cm (up to 50 cm) containing 5–20 seeds in each pod (Sahoo et al. 2002). The globular shaped shining seeds may be white, yellow, brown, black or mottled and vary in weight from 0.06 to 0.5 g each. All parts of the plant, i.e. seeds, flowers, leaves, pods and tuber-like roots, are edible. The young tender pods can be stewed, boiled, fried, roasted or made into milk. The seeds contain 40% proteins, and the roots contain about 20% proteins, which are supposed to be ten times more than in potatoes or yams. Winged beans are also rich in carbohydrates and vitamin A (300–900 IU). Its tender leaves make good sauce and curry. Ningombam et al. (2012) reported highest K (8.9 mg/g), Ca (8.06 mg/g) and Mg (5.72 mg/g) in the mature pods. Flowers have a sweet taste because of the nectar they contain. The tuber-like roots are eaten after boiling or frying. The plant is a good fodder for cattle (Rai et al. 2005).

Velvet bean (*Mucuna pruriens*): This crop is grown in north-eastern states for vegetables as well as medicinal purpose and also occurs in wild form. The possibility of utilizing velvet beans as a commercial source of L-DOPA (which is relatively expensive to produce synthetically), used in the treatment of Parkinson's disease, has received attention in recent years. The seed can be used as a feed for pig and poultry. The residual cake has a protein content of 15–20%. Seventy-nine collections of velvet bean were collected and evaluated by the ICAR Research Complex for NEH region, Meghalaya. Wide range of variability was observed for the growth and yield-attributing traits. Days to flower initiation ranged from 48 days (UKDMP-7) to 123 days (NGLMP-25). Highest seed yield per plant was recorded from the collections WBNMP-6 (2.47 t/ha) followed by NGLMP-25 (2.42 t/ha), MZRMP-03 (2.31 t/ha), UPMP-06 (2.22 t/ha) and WBNMP-3 (2.0 t/ha). The highest L-DOPA content in seeds was in the collection UKDMP-11 (6.54%) followed by MGHMP-25 (5.87%).

Sohphlang (*Flemingia vestita*): It is one of the most important leguminous minor tuber crops. It is grown as a cash crop in the north-eastern part of the country, especially in the *Khasi* and *Jaintia* hills of Meghalaya. Sohphlang, being a leguminous tuber crop having symbiotic association with the Rhizobium spp. in root nodules, fixes the atmospheric nitrogen in the soil. Gangwar and Ramakrishnan (1989) reported that under mixed cropping system, it fixed 250 kg nitrogen per hectare per year. Most of the tuber crops like sweet potato, colocasia and sohphlang having good surface cover protect the soil from water erosion. It is mostly grown traditionally under *Jhum* land as a pure as well as mixed crop during March–April to October–November. The tubers of *Sohphlang* are eaten as raw either with salt and some red chilli powder, and the best combination is with Nei Lieh (*Perilla frutescens*), which is ground to a fine paste together with salt. The tubers of *Flemingia vestita* are rich in iron (2.64 mg/100 g) and phosphorous (64.06 mg/100 g) and contain a fair amount of protein (2.99 g/100 g), calcium (19.77/100 g) and carbohydrates (27.02 g/100 g) (Sarma 2001). Being a leguminous crop, it enriches the soil fertility and protects the soil from erosion. Crop is also hardy in nature and grown as a rainfed crop. Plants also have symbiotic association with nitrogen-fixing bacteria as well as several species of fungi. Songachan and Kayang (2013) reported a total of 61 arbuscular mycorrhizal fungi (AMF) species (51 from natural site and 46 from cultivated site) belonging to six genera (*Acaulospora, Ambispora, Gigaspora, Glomus, Pacispora and Scutellospora*) associated with *F. vestita* rhizosphere soil. The crop is also known for traditional medicine as vermifuge. Tuber peel extract was found most effective against helminthic parasite, including the nematodes such as *Ascaris suum*, *Ascaris lumbricoides*, *Ascaris diagalli*, *Heterakis gallinarum*, a cestode *Raillietina echinobothrida* and trematodes such as *Paramphistomum* spp. (Tandon et al. 1997) and *Artyfechinostomum sufrartyfex* and *Fasciolopsis buski* (Roy and Tandon 1996). Rao and Reddy (1991) isolated an isoflavone, genistein, from the tuber peel extract, which was found as the major anthelmintic principle, highly potent against trematodes and cestodes. It was further tested and found effective against the sheep liver fluke *Fasciola hepatica* (Toner et al. 2008) and human tapeworms such as *Echinococcus multilocularis* and *E. granulosus* metacestodes (Naguleswaran et al. 2006). The peel and its active component, genistein, have been shown to cause flaccid paralysis, deformity of tegumental architecture and alterations in the activity of several enzymes in platyhelminth parasites (Pal and Tandan 1998; Kar et al. 2002). It is also a rich source of other bioactive isoflavones such as daidzein, formononetin and pseudobaptigenin.

Tree bean (*Parkia roxburghii* G. Don.): Locally known as Yongchak (Manipur), Yontak (Assam), Unkamn-pinching (Naga), Aoelgap (Garo) and *Zawngṭah* (Mizo), it is one of the most important leguminous multipurpose tree species grown most widely in Manipur and Mizoram. *P. roxburghii* has been hitherto denoted by different scientific names, such as *Parkia timoriana*, *P. javanica* and *P. biglobosa* (Helen 1994). The flowers are used as a salad and pod as a vegetable, which is found in wild form in Nagaland (Deb et al. 2013). The crop starts bearing at 8–10 years after planting. Pods are formed in clusters of 10–15, each measuring 25–40 cm in length and 2–4 cm in breadth (Kumar et al. 2002). During favourable season, a full-grown plant bears 10,000–15,000 pods. It is available from December until March, and consumption starts from the tender pods, when it is about 30 cm long until maturity. It is consumed either fresh or cleaned and sun-dried for future use during off seasons. It is also consumed raw along with condiments or cooked with other vegetables or meat. It has significant economic value as vegetable, medicine, industrial material and firewood in this region. It is fast growing, easier to grow and hardy in nature. It produces a crop even under adverse soil and climatic conditions. This tree is suitable for reclamation of abandoned *Jhum* lands and also as agroforestry plantations. If properly exploited, it can serve as a supplementary source of vegetable proteins and edible oil. It contains 28.8% and 13–19% of protein in kernel and pods, respectively. Similarly, highest content of fat (34%) is in the kernel and ranges from 1 to 16% in the pods. Unsaturated fatty oleic, linoleic and linolenic acids make up 63–68% of the total fat in the pods as well as the kernels. The total essential amino acids amount to 33%, 36% and 39% in the tender, immature and mature pods, respectively, and 42% in the kernels. However, the amino acid scores of the tender, immature and mature pods were 64, 84 and 92, respectively, with sulphur amino acids as the limiting amino acids in all the pod samples (Longvah and Deosthale 1998). The pods also contain good amount of Fe (57.1 mg/100 g) and Mn (35.0 mg/100 g). Besides, it also contains higher amount of total phenolic content 79.63 GAE and flavonoid (4.35 mg g^{-1}) content (Tapan 2011).

Agati (*Sesbania grandiflora* (L.) Poiret): It is a perennial legume tree crop grown in wild and cultivated forms in NE states of India. It is a multipurpose crop; flowers and leaves are used for cooking purpose. According to the USDA, the edible flower contains 1.28 g/100 g protein and 102 μg/100 g folate. The leaves are an excellent source of calcium (1130 mg/100 g) and iron (4 mg/100 g). *S. grandiflora* has excellent root nodulation and hence fixes nitrogen, although this ability may be suppressed by nematodes or high acidity of the soil.

15.1.2 Solanaceous Crops

Eggplant (*Solanum* spp.): Brinjal or eggplant is an important indigenous group of solanaceous vegetable crop. The *Solanum* sp. includes edible (*S. melongena*; *S. aethiopicum* var. *gilo*; *S. macrocarpon*) and nonedible (two *S. indicum*; one *S. torvum*; one *S. khasianum*) species. There is a wide range of variability within and between the species. Regarding nutritional value, eggplant has a very low calorific value and is considered among the healthiest vegetables for its high content of vitamins, minerals and bioactive compounds for human health (Raigón et al. 2008; Plazas et al. 2014; Docimo et al. 2016). In this respect, eggplant is ranked among the top ten vegetables in terms of oxygen radical absorbance capacity (Cao et al. 1996). The bioactive properties of eggplant are mostly associated with high content in phenolic compounds (Plazas et al. 2013), which are mostly phenolic acids, particularly chlorogenic acid in the fruit flesh (Stommel et al. 2015) and anthocyanins in the fruit skin (Mennella et al. 2012). Both phenolic acids and anthocyanins have multiple properties beneficial for human health (Plazas et al. 2013; Braga et al. 2016). It also possesses several medicinal properties such as analgesic, anti-inflammatory, antiasthmatic, anti-glaucoma, hypoglycaemic and hypolipidaemic properties (Odetola et al. 2004). These pharmacological properties have been attributed to the presence of certain chemical substances in the plants, such as fibre, ascorbic acid, phenols, anthocyanin, glycoalkaloids and α-chaconine (Sanchez-Mata et al. 2010). Their uses in indigenous medicine range from weight reduction to treatment of several ailments including asthma, allergic rhinitis, nasal catarrh, skin infections, rheumatic disease and swollen joint pains, gastro-oesophageal reflux disease, constipation and dyspepsia (Bello et al. 2005).

The wild species (*S. gilo*) is also grown by farmers for fruits, and a wide variability for the yield and quality traits is observed. Sanga et al. (2017) observed maximum fruit weight (27.86 g), total carbohydrate (375.78 mg/100 g), ascorbic acid content (16.73 mg/100 g) and total alkaloid (4.68 mg/100 g) in accession CHFG-4. CHFG-5 was superior for the number of fruits per plant (93.66), fruit yield per plant (1.97 kg) and total phenol (15.27 mg/100 g).

African eggplant (*S. macrocarpon*) is also grown widely for fruits as well as leaf for cooking. Oboh et al. (2005) observed higher protein (4.3%), fat (0.6%) and crude fibre (1.4%) content in the leaves of *S. macrocarpon*. Verma et al. (2019a, b) observed wide variability for the cultivated and wild species of the eggplant species. The local eggplant accessions (Bhola Nath, RCMB-10, Singh Nath and RCMBL-1) were found highly stable for yield with lowest wilt incidences when compared to other Indian accessions, and these accessions can be used for commercial production and also resistance breeding.

Besides, wild species *S. torvum* and *S. indicum* fruits are also used for the preparation of chutney by some tribes of the region. Moreover, *S. torvum*, a highly resistant species of eggplant to bacterial wilt, can be used as a root stock for the grafting of the cultivated brinjal. Further, *S. khasianum* is known for medicinal properties due to the presence of solasodine (1.0–1.25%), which is used in the manufacture of corticosteroid hormones. Solasodine is also used in the manufacture of several drugs, the hormones of which are used as active ingredients in contraceptive pills. Genotypes RRL-20-2, RRL-SL-6, Glaxo, Arka Sanjivini and Arka Mahima are found suitable for commercial cultivation.

Capsicum spp.: There is a wide range of variability in the landrace of *Capsicum* spp. in the region. The popular landraces of *Capsicum* spp. are hot pepper, king chilli, bird's-eye chilli, dalle chilli and cherry chilli. Among the landraces, the highest average capsaicin content on dry weight basis was observed in king chilli (4.30%) followed by bird's-eye chilli (3.80%), dalle chilli (3.42%) and chillies (1.53%). Similarly, oleoresin content was also highest in king chilli (28.98%) followed by dalle chilli (21.18%), bird's-eye chilli (19.21%) and chilli (15.52%). The β-carotene content (μg g^{-1} FW) in red ripe fruits was highest (375.16) in dalle chilli followed by king chilli (338.66), bird's-eye chilli (308.45) and chilli (31.65). Positive correlation was observed between antioxidant activities to capsaicin, oleoresin and β-carotene content. Among the landraces, king chilli was found superior for both capsaicin and oleoresin content followed by bird's-eye chilli for capsaicin and dalle chilli for oleoresin content under protected conditions. Moreover, the high-yielding accessions for yield per plant were identified as king chilli-1 (819.5 g), SKCC-1 (416.6 g), MZBEC-1 (181.0 g) and MLCC-22(332.0 g) of king chilli, dalle chilli, bird's-eye chilli and chilli, respectively. The identified accessions rich in capsaicin and oleoresin content as well as yield can be promoted for the commercial production and in crop improvement (Verma et al. 2021).

Tree tomato (*Cyphomandra betacea*), a perennial solanaceous crop, is grown in backyard for the ripe fruits and used for preparation of chutney and also in cooking as a substitute for tomato. Fruits are juicy and rich in protein (2.0 g), vitamin A (630 IU), vitamin C (29.8 mg) and vitamin K (321 mg) content. Nagaland Government has received the geographical indicator for the crop. Lycopene content in tree tomatoes is very high as it is 5.47 mg/100 g in red cultivars and 6.32 mg/100 g in yellow cultivars, which acts as an antioxidant, and it is a great addition to any man's health regimen. Tree tomatoes are also rich in carotenoids, leading to high antioxidant activity. It is also very rich in ascorbic acid content, and these compounds are linked with possible health benefits, such as reducing the risk of cancer and cardiovascular diseases. Both red and yellow tree tomatoes have similar phenolic composition except for anthocyanin, which is very high in red varieties, i.e. 7.2 mg/100 g, whereas it is absent in the yellow cultivars, and due to the high anthocyanin content in the dark red cultivars, the skin has a purplish tinge.

15.1.3 Cole Crops (*Brassica oleracea*)

Among the cole crops, cabbage, cauliflower and broccoli are widely grown in the region. In the north-eastern region, cabbage is the leading crop and contributes about 10.7% and 18.17% of the total area and production under vegetable crops followed by cauliflower with 5.7% and 9.28%, respectively. There are local landraces of cauliflower grown in the region, especially in parts of Meghalaya, and seeds are also produced locally in East and West Khasi Hills districts. The local landrace is of long duration (>120 days) for harvesting with marketable curd yield of 1.5–2.0 kg/plant. For cabbage and broccoli, the seeds are purchased from the market and the high-yielding varieties/hybrids are Italian Green, Pushpa, Fiesta, Aishwarya (Broccoli), Wonder Ball and H-139 (cabbage).

15.1.4 Cucurbits

There are many cucurbit crops grown in the region such as cucumber, pumpkin, bottle gourd, ash gourd, momordica species (*Momordica charantia*, *M. charantia* var. *muricata*, *M. cochinchinensis*, *M. subangulata* subsp. *renigera*, *M. cymbalaria*), luffa and chow-chow.

Among these cucurbits, cucumber, spine gourd, bitter gourd, luffa and ash gourd are indigenous crops, and wider variability has been observed for the different yield and quality traits. The wild ancestor of cucumber, *Cucumis sativus* var. *hardwickii*, is found in natural habitats in the foothills of the Himalayas and Northeast region, particularly in Meghalaya. This species is a potential source for resistance to downy mildew and root-knot nematode. Accessions (IC410617, IC527419 and IC538130) from Tripura have been found to be free from downy mildew symptom. IC410617 was observed to be resistant to viral disease. Wild species of cucumber *Cucumis hystrix* has also been found to be an important source of resistance to downy mildew. Two unique cucumber accessions (IC 420405 and IC 420422) from Mizoram state having orange flesh showed high carotenoid content (Ranjan et al. 2013). *Cucurbita ficifolia* is found in Meghalaya (Pradheep and Singh 2015), which is a potential source for grafting of cucumber against moisture stress and low temperature.

Ucche (*Momordica charantia* L. var. *muricata* Willd): It is also very popular in the region, especially Assam, Bengal and Tripura. Although it is low in calorific value, it is rich in several nutraceutical properties, as it possesses antidiabetic, anti-ulcerogenic, anti-mutagenic, antioxidant, anti-tumour, anti-lipolytic, analgesic, abortifacient, antiviral, hypoglycaemic and immunomodulatory properties. In vitro studies have shown that the bitter gourd proteins (α-and β-momorcharin) have inhibitory effect against HIV virus. Medicinal value of bitter melon has been attributed to its high antioxidant properties due in part to phenols, flavonoids, isoflavones, terpenes, anthraquinones and glucosinolates, all of which confer a bitter taste.

Teasel gourd (*Momordica subangulata* subsp. *renigera*): It is grown widely, specially in Barak and Brahmaputra valleys and up to mid-hills of the region. It is also considered to have cooling, analgesic, sedative, hypoglycaemic and diuretic properties and balances all the three doshas. It also protects and regenerates pancreatic β-cells. Additionally, it enhances both insulin secretion and insulin sensitivity, helping to manage diabetes at all levels. Besides, spine gourd possesses anti-allergic, antioxidant, antibacterial and anti-inflammatory properties. It supports all functions of the immune system such as scavenging of the microbes, memory function of the immune system and also being killer cells.

Chow-chow (*Sechium edule*): It is a multipurpose crop, grown for its tender shoots, fruits and tuberous roots. It also has several medicinal properties due to the presence of polyphenol. The crop is rich in flavonoids, especially in leaves (35.0 mg/10 g dried leaves) followed by roots (30.5 mg/10 g) and stems (19.3 mg/10 g) (Siciliano et al. 2004). It also contains Sechiumin, an anticancer ribosome-inactivating protein (Th et al. 1998). Besides, fruit extract also has antihypertensive effect (Gordon et al. 2000); antibacterial, antifungal and antioxidant activities (Ordonez et al. 2003, 2009; Sibi et al. 2013); and antihyperglycaemic (Tiwari et al. 2013), anticonvulsant and central nervous system depressant activities (Firdous et al. 2012). Likewise, teasel gourd fruits are also rich in β-carotene (162 mg/100 g) and phenol content (36 mg/100 g GAE).

Among the underutilized cucurbits, ICAR Research Complex for NEH Region, Umiam, Meghalaya, is maintaining diverse accessions of chow-chow (74) and teasel gourd (50), and Mizoram Collection-1 (39.0 kg/plant) and RCTG-8 (2.6 kg/plant) have been identified as high-yielding accessions, respectively. The Institute has also developed a value-added product tooty-fruity of chow-chow fruits, which can be promoted for commercial production.

15.1.5 Okra

Okra is also an important warm-season vegetable crop grown widely in the region. It is rich in protein (2.0%) and dietary fibre (3.2%), folic acid (60 μg/100 g) and minerals like calcium (Ca), phosphorus (P) and iron (Fe) at different amounts of 84, 90 and 1.20 mg/100 g, respectively. It also possesses β-carotene, riboflavin and vitamin B complex at approximate concentrations of 185 μg, 0.08 mg and 0.04 mg, respectively. Mucilage, a thick, gel-like substance found in okra, can bind with cholesterol during digestion, so it is passed from the body. There is wider variability in the cultivated species of okra. *Abelmoschus crinitus* and *A. pungens* wild species are also distributed in the north-eastern region of India. *A. crinitus* has shown resistance to yellow vein mosaic viruses (YVMV), okra enation leaf curl virus (OELCV) and Cercospora blight (Singh et al. 2007) and can be used for crop improvement.

15.1.6 Leafy Vegetables

There are numerous leafy vegetables grown in the region, during winter and summer/rainy season.

Mustard green: It is popularly known as laipatta (*Brassica juncea* var. *rugosa*) and is a very popular cool-season vegetable. There is a wide range of variability for the leaf yield and quality characteristics. ICAR Research Complex for NEH region maintains ten accessions, and of these, Megha Laipatta-1 (green leaves) and Megha Laipatta-2 (purple leaves) have been found to be high yielding (25.0 t/ha each). Recently, a variety UHFVR12-1 tested under AICRP on vegetable crops has been found to be suitable for the region and recommended by the Central Sub-Committee on Crops Standards, Notification and Release of Varieties of Horticultural Crops, in 2021. Mustard green is rich in nutritional values, especially in crude fibre (11–12.5%), protein (28%) and vitamin A (10,000–12,000 IU) content.

Lettuce: This crop is also grown widely in the region during September–March, and farmers depend on the market seeds. Among the growers, the popular variety is Iceberg, under AICRP trials at ICAR Research Complex for NEH Region, Umiam, Meghalaya; out of 6 accessions, the highest gross yield (133 q/ha) was recorded from entry 2018/LETVAR-3 followed by 2018/LETVAR-4 (123 q/ha). There is huge potential for the commercial production of the crop, and market price ranges from Rs. 40 to 120/kg. Lettuce is consumed fresh as a salad and is found to be rich in dietary fibre (1.3%) and vitamins, especially folates (38 μg), vitamin A (7405 IU), vitamin K (126.3 μg) and phyto-nutrients β-carotene (4443 μg) and lutein-zeaxanthin (1730 μg) from 100 g of green leaves (USDA).

Malabar spinach: *Basella alba* popularly known as *Poi* is another important warm-season leafy vegetable grown widely in the valleys of the region, which is a rich source of dietary fibre (32 and 10 g/100 g DW) and protein content (1.8%). It is also a rich source of pigments lutein (107 μg/100 g) and β-carotene (1620 μg/100 g) along with betalains (80 mg) and antioxidant properties with the EC50 values (3.4 mg/mL) for DPPH radical scavenging activity (Kumar et al. 2015). The mucilage present in *Basella alba* also has hypoglycaemic activity. It has been attributed with gastro-protective, ulcer healing, anti-inflammatory activity and wound-healing activity.

Amaranth: Chaulai (*Amaranthus* spp.) is also an important warm-season leafy vegetable crop grown widely in the entire north-eastern states. It is rich in crude protein (2.11%), crude fibre (1.93%) and minerals such as calcium 330 mg/100 g, Fe 18.2, Mg 1842, P 52, K 3460, Na 108, Zn 10, Cu 300, Mn 8, Se 1.98 and Cr 0.92 mg (Sharma et al. 2012).

***Allium* spp.:** Over 11 species of genus allium have been reported in the region, viz. *Allium chinense, A. hookeri, A. tuberosum, A. fistulosum, A. ascalonicum, A. macranthum, A. prattii, A. rubellum, A. wallichii, A. sativum and A. cepa*. (Devi et al. 2014). *A. chinense* (Chollng) contains about 2.6% protein, 0.6% fat, 2.4% carbohydrate and 0.95% ash with small amounts of vitamins A, B_1 and C. Among the Allium species, *Allium hookeri* (Maroi napakpi) has shown therapeutic values due to the higher concentration of total phenols (2 g/100 g dry wt.) and phytosterols (0.5 g/100 g) that are known to lower the intestinal absorption of cholesterol.

15.1.7 Aromatic Plants

There are many aromatic leafy vegetable species grown in the region for aroma in several cuisines like vegetables, meat and soup.

Basil (*Ocimum* spp.): The basil belongs to the mint family (Lamiaceae, formerly called Labiatae) of the flowering plants, with 236 genera and more than 7000 species, the largest family of the order Lamiales known for aromatic leaves. Sweet basil (*Ocimum basilicum*), clove basil (*Ocimum gratissimum* L.) and mint (*Mentha* spp.) are very popular species among them. Lamiaceae is distributed nearly worldwide, and many species are cultivated for their fragrant leaves and attractive flowers. The family is particularly important to humans for herb plants useful for flavour, fragrance or medicinal properties. Aroma is due to essential oil having 1,8-cineole, geraniol, estragole and eugenol as potential antioxidants. These plants possess many medicinal properties and are used to sharpen memory, as a nerve tonic, and remove phlegm from bronchial tubes. Boiling basil leaves with honey and ginger is used for treating asthma, bronchitis, cough, cold and influenza. They are also rich in polyphenol (126 mg/g) content. It also possesses antimicrobial, antiviral and anticancerous properties.

Spanish coriander (*Eryngium foetidum*): It is popularly known as Naga dhania and is a tropical perennial herb in the family Apiaceae. Plants are cultivated for the aromatic leaves in India and other Southeast Asian countries and is rich in essential oils containing E-2-dodecenal (eryngial). It possesses anthelmintic activity due to eryngial, anti-inflammatory action due to the phytosterol fractions, anticonvulsant activity in the respective models and selective antibacterial activity against Salmonella species and the Erwinia genus of bacteria (Paul et al. 2011).

Perennial aromatic plants: There are two perennial plant species of Rutaceae family, cultivated for their aromatic leaves, i.e. *Murraya koenigii* (curry leaf) and *Zanthoxylum* spp. The essential oils from the *Murraya koenigii* (curry leaf) and *Zanthoxylum* spp. possess antioxidant activity. Curry leaves are rich in folic acid (23.5 mg/100 g) and oil having crystalline glucoside Ksenigin. The fresh and dried leaves are used for the seasoning of foods such as meat and chicken curry, and they are rich in essential oils (2–3%) along with minerals.

Tuber crops: The region also has wider area under different tuber and rhizomatous crops such as potato, taro (Arvi/Bunda), Xanthosoma, sweet potato, tapioca, Dioscorea and sohphlang. Among the tuber crops, potato is a leading crop and contributes 27.3% and 20.4% of the total vegetable area and production, respectively, followed by tapioca, sweet potato and colocasia.

Tuber crops produce large quantities of energy (carbohydrate) in relatively less time than other crops. They are most efficient in converting solar energy, for example cassava producing 250 × 103 kcal/ha and sweet potato 240 × 103 kcal/ha as compared to 176 × 103 for rice, 110 × 103 for wheat and 200 × 103 for maize. Cassava contains 20–40% starch and about 70% moisture. However, when dry, it contains 73% starch and gives a theoretical ethanol yield of 0.45 L kg^{-1}. Cassava starch can be easily hydrolysed to sugars for production of fermentation-based products. Cassava starch costs 15–30% less to produce per acre than corn starch, making cassava an attractive and strategic source of renewable energy (Hankoua and Besong 2009). Unlike corn, sweet potato and cassava require less fertilizer and pesticide and the yield approaches the lower limit of those produced by sugarcane (Schill 2008).

The tuber crops have an important role in nutritional security, especially energy malnutrition (Table 15.2). Potato contains good amounts of essential amino acids

Table 15.2 Proximate composition of tuber crops (grams per 100 g on dry weight basis)

Crops	Protein	Fat	Minerals	Fibre	Carbohydrates
Potato	1.87	0.1	–	1.8	20.13
Sweet potato	3.6	0.8	3.0	2.3	88.0
Cassava	1.7	4.9	2.5	1.5	84.9
Yam	4.7	0.3	5.3	3.3	86.6
Colocasia	11.6	0.4	6.3	3.7	78.5
Elephant-foot yam	5.6	0.5	3.8	3.8	86.3
Colocasia leaves (black types)	31.9	9.4	11.8	8.5	38.0
Colocasia leaves (green types)	22.6	8.7	12.8	16.8	39.4

like leucine, tryptophan and isoleucine (Paul Khurana and Naik 2003). It yields about 97 kilo calories per 100 g fresh weight, which is much than cereals. Several nutritional disorders due to deficiency of vitamins A and C and calcium could be easily alleviated by consumption of root and tuber crops like cassava, sweet potato, yam and aroids. Root and tuber crops are rich in vitamins and minerals. On an average, cooked yam has about 2% protein, cassava and sweet potato provide ascorbic acid (vitamin C) whereas cereal-based foods have none. Sweet potato also contains important amino acids, while rice is deficient in lysine. The orange- and yellow-fleshed sweet potato roots and green tops are a good source of vitamin A, which can prevent night blindness and malnutrition that is prevalent. Besides, sweet potato is rich in antioxidants, nutrients like β-carotene, ascorbic acid (vitamin C) and tocopherol (vitamin E), which can prevent coronary disorder and cancer. Elephant-foot yam (*Amorphophallus campanulatus*) is used as a food as well as a medicine. It will not create any gastrointestinal problems. Its various therapeutical applications can be seen in diseases like piles, dysentery and gas trouble. Yam is an important tuber crop of the region; about 28 species and 25 varieties in Dioscorea have been reported from the region mainly in the Garo Hills (Hore and Sharma 1995). The major species found in the region are *D. alata, D. esculenta, D. bulbifera, D. pentaphylla, D. hamiltonii, D. cylindrical, D. sativa, D. oppositifolia*, *D. deltoidea* and *D. floribunda*, and it is mainly grown by tribal farmers in their *Jhum* field. *D. floribunda* and *D. deltoidea* are grown for their medicinal value. They are a good source of corticosteroids, e.g. sapogenins and oral contraceptives. The steroidal hormone, cortisone, used in rheumatic illness and ophthalmic problems is derived from *D. deltoidea*. *D. alata* cultivar Orissa Elite has been identified as high yielding for the region.

The region is hotspot of late blight of potato, and popular cultivars resistant to late blight are Kufri Jyoti, Kufri Girdhari, Kufri Himsona, Kufri Megha, Kufri Khasi Garo and Kufri Giriraj. ICAR Research Complex for NEH Region, Umiam, conserves 40 accessions of taro, 2 accessions of Xanthosoma and 32 accessions of sweet potato. In recent past, two varieties of taro, i.e. Megha Taro-1 and Megha Taro-2, were found to have rich starch content with less oxalate and tolerant to leaf blight. Sweet potato variety ST-14 has been found to be rich in β-carotene (13.23 mg/100 g) and can be promoted for commercial production to ensure the nutritional requirements of vitamin A. Under CIP-IFAD-funded project Food START, the Institute has identified over >16 diverse accessions of the colocasia at household level from the project site Rombagre of Garo Hills in Meghalaya, and each one is grown for a specific purpose having unique traits. Landrace Tamachongkam is very popular, and tuber is used for the curry and leaves for pig feed. Likewise, landrace Rengama, a bunda-type genotype, is very popular for curry preparation, and Tasekrek and Tamachok are boiled and used as snacks. *Xanthosoma* spp. (landrace White Ganima and Purple Ganima) is grown for the petioles. Chigi, a bush-type colocasia, is grown nearby kitchen and leaves are used during off season when there are no other leafy vegetables.

15.2 Perennial Fruits

Jackfruit (*Artocarpus heterophyllus*): There is wider variability in the region, and due to mild weather, it is available almost round the year with huge market potential for the supply in off season in other parts of the country. The fruits are rich in nutritional values like carbohydrates (24.0%), protein (1.7%) and dietary fibre (1.6%) and low in fats (0.6%) with high content of omega-3 fatty acids (24.0 mg) and omega-6 fatty acids (63.0 mg), vitamin A (297 IU) and minerals like potassium (303.0 mg) and phosphorus (36.0 mg) from 100 g raw samples. The cooked vegetables are suitable for the diabetic patient as they have glycaemic index of 75 and a medium glycaemic load (USDA).

Ferns: There are 23 ferns and fern allies which have been found to be edible and used in preparing various cuisines. They are used for salad, cooking and value-added products such as pickle, fermented fish and pork. Four species, viz. *Diplazium esculentum* (Retz.) Sw., *Huperzia phlegmaria* (L.) Rothm., *Huperzia squarrosa* (G. Forst.) Trevis. and *Nephrolepis cordifolia* (L.) C. Presl, are cultivated in small scale for consumption (Yumkham et al. 2016). The ferns are rich sources of protein, and among the species, the maximum protein content has been recorded from *Tectaria coadunata* (12.10%). The widely used fern species *D. esculentum* (fiddle-head fern) contains 4.55 g of protein, 0.32 mg of copper, 4.98 mg of niacin, 26.6 mg of ascorbic acid and 181 μg of vitamin A in 100 g fresh leaves. Besides, they are also rich in minerals such as sodium (0.46–3.56 mg), magnesium (6.42–13.39 mg) and iron (10.36–16.35 mg) (Chettri et al. 2018).

Bamboo shoots: With about 136 species, India is one among the richest countries in bamboo resources that help mankind in more than 1500 diverse ways. North-Eastern Himalayan (NEH) region of India has a great diversity of bamboo resource, and the tribal communities of the region use young succulent shoots of various bamboo species as vegetable, pickles, salad, etc. from May to September every year. Out of 25 edible bamboo species identified for the region, 11 species, i.e. *Bambusa balcooa* Roxb., *B. nutans* Wall. ex Munro, *B. tulda* Roxb., *Dendrocalamus giganteus* Munro in Trans., *D. hamiltonii* Nees et. Arn, *D. hookeri* Munro in Trans., *D. longispathus* Kurz, *D. sikkimensis* Gamble, *Melocanna baccifera* (Roxb.) Kurz, *Phyllostachys bambusoides* Sieb. and Zucc. and *Teinostachyum* *wightii* Beddome, have been found as potential species, which are sold in the markets by primary or secondary vendors in fresh, fermented, boiled or roasted form (Bhatt et al. 2005). Although the utilization of juvenile shoots of bamboo in tribal diet of Northeast India is a very old observable fact, its numerous health benefits and potentiality remain uncharted. Apart from being delicious, the bamboo shoots are also rich in minerals and nutrient components such as carbohydrates (4.20–6.10%), proteins (1.30–2.30%) and fibre (0.50–0.77%) and are low in fat and sugar, which could be helpful in mitigating the problem of malnutrition. Among the species, *Bambusa balcooa*, *Bambusa pallida* and *Melocanna baccifera* are grown in Northeast India, mainly for edible shoots (Basumatary et al. 2017). The juvenile shoots of *Dendrocalamus hamiltonii* have the highest protein content (3.69%) followed by *Bambusa bambos* (2.93%). They are also found to be a good source of vitamin E (a tocopherol), vitamin C (3.0–12.9%), B6 (0.01%), thiamine (0.05%), riboflavin (0.01%) and niacin (0.03%) along with vitamin A (20 IU), vitamin B1 (0.15 mg/100 g) and vitamin B3 (0.60 mg/100 g) (Nirmala et al. 2007; Choudhury et al. 2010). In the shoots of *Dendrocalamus giganteus*, magnesium (Mg), a life-supporting element that plays an indispensable role in body metabolism, is found in higher content ranging from 5.38 to 140 mg/100 g (Bhatt et al. 2005). Bamboo shoot also has a higher amount of 'selenium (Se)', which is essential for fertility and normal growth. Selenium has close metabolic relationship with vitamin E for treating diseases, and hence it is also known as 'miracle life element' (Chongtham et al. 2011; Thounaojam et al. 2015). Due to the presence of lignins which are an important component of fibre, the shoots of the bamboo are reported to have anticancer, antiviral and antibacterial activity (Tamang et al. 2012). Bamboo is also labelled as a 'heart-protective vegetable' because of its high content of potassium (K), which helps in maintaining normal blood pressure. It also prevents constipation and decreases body fat (Chongtham et al. 2011).

Mushrooms: The region is also rich in different cultivated and wild edible mushrooms. Among the cultivated mushrooms which are widely grown are oyster mushroom (*Pleurotus sajor-caju (P. pulmonarius), P. florida, P. sapidus, P. citrinopileatus, P. flabellatus, P. eryngii, P. ostreatus, P. fossulatus, P. djamor, P. membranaceus* and *P. cornucopiae*), paddy straw mushroom (*Volvariella volvacea*), button mushroom (*Agaricus bisporus* and *A. bitorquis*), milky mushroom (*Calocybe indica*), shiitake mushroom (*Lentinula edodes*), Jew's-ear mushroom (*Auricularia* spp.) and blue oyster mushroom (*Hypsizygus ulmarius*) (Baiswar et al. 2016a, b; Chandra et al. 2001; Rangad 1995). Paddy straw, which is commonly used as a substrate for oyster mushroom cultivation, is available in plenty in the NE region. The popular wild mushroom species are *Ramaria* sp., *Termitomyces* spp., *Gomphus* sp., *Cantharellus* sp., *Lyophyllum* sp. and *Laccaria* sp. These mushrooms are in great demand due to their nutritional values (Table 15.3), as they are also a good source of vitamins with high levels of riboflavin (vitamin B_2), niacin, folates and traces of vitamins C, B_1, B_{12}, D and E. Mushrooms are the only nonanimal food source that contains vitamin D, and vitamin D enrichment can be done by sun-drying. Hence, they can also be promoted for enrichment and diversification of the diet of the local population as well as utilization of agricultural waste for the

Table 15.3 Nutritional values of different mushroom species (g/100 g DW)

Mushroom species	Carbohydrate	Fibre	Protein	Fat	Ash	Energy kcal
Agaricus bisporus	46.17	20.90	33.48	3.10	5.70	499
Auricularia auricula	82.80	19.80	4.20	8.30	4.70	351
Calocybe indica	64.26	3.40	17.69	4.10	7.43	391
Flammulina velutipes	73.10	3.70	17.60	1.90	7.40	378
Lentinula edodes	47.60	28.80	32.93	3.73	5.20	387
Pleurotus ostreatus	57.60	8.70	30.40	2.20	9.80	265
Pleurotus sajor-caju	63.40	48.60	19.23	2.70	6.32	412
Volvariella volvacea	54.80	5.50	37.50	2.60	1.10	305

Source: Manikandan (2011)

Table 15.4 Medicinal properties of mushrooms

Mushroom species	Compounds	Medicinal properties
Ganoderma lucidum	Ganoderic acid and β-glucan	Improve immune system, antibiotic properties, inhibit cholesterol synthesis
Lentinula edodes	Eritadenine and lentinan	Lower cholesterol and anticancerous
Agaricus bisporus	Lectins	Enhance insulin secretion
Pleurotus sajor-caju	Lovastatin	Lower cholesterol
Ganoderma frondosa	Polysaccharide lectins	Antidiabetic properties
Auricularia auricula	Acidic polysaccharides	Decrease blood glucose
Flammulina velutipes	Ergothioneine and proflamin	Antioxidant and anticancer activity
Trametes versicolor	Polysaccharide-K	Decrease immune system depression
Cordyceps sinensis	Cordycepin	Antidiabetic, antidepressant activity

Source: Manikandan (2011)

commercial production of mushrooms. Major issue with mushroom cultivation is the availability of quality spawn. Availability of quality spawn can greatly enhance mushroom cultivation in this region. Information in vernacular language is also the need of the hour for increasing mushroom production. We have published Technical Bulletin in Khasi language to remove these lacunae (Baiswar et al. 2016a, b). Information related to fungal parasites, competitor moulds and pests has also been documented since they are limiting factors in mushroom production, especially during rainy season (Baiswar et al. 2014; Nongkynrih et al. 2017).

There are many species of mushrooms, which possess several medicinal values (Table 15.4). Mushrooms are also known as treasure trove for bioactive compounds like alkaloids, carotenoids, enzymes, fats, folates, glycosides, lectins, minerals, organic acids, phenolics, polysaccharides, proteins, terpenoids, tocopherols and volatile compounds, which can be used for health benefit. Most studied species of mushrooms for bioactive compounds are *Ganoderma lingzhi, Ophiocordyceps sinensis, Phellinus linteus* and *Xylaria nigripes* (Niego et al. 2021). Many bioactive compounds found in various mushroom species possess properties of being hepatoprotective, anti-ageing, antioxidant, antitumor, immunostimulatory, neuroprotective, hypoglycaemic, antidiabetic, memory enhancement, gastro-protective, anti-inflammatory and renoprotective (Niego et al. 2021).

15.3 Biodiversity of Mushrooms

Northeast region is very rich in mushroom species, both edible and nonedible. Even nonedible mushrooms also need documentation since they can be excellent sources of various genes and pharmaceuticals, which can be used for the benefit of mankind. Many genera and species have been reported from the northeast region. The following list of genera is compiled from the mushroom museum being maintained at ICAR Research Complex for NEH Region, Umiam, and other sources (Verma et al. 1995) (Table 15.5).

15.4 Conclusion

The diverse climate of the region provides an ample opportunity for the conservation and uses of the wide range of vegetable crops and species. The diverse vegetable crops also have huge potential for the nutritional security by diet diversification and fortification, as they are rich sources of several macro- and micronutrients and have ethnobotanical uses, besides employment and economic upliftment. Moreover, there is urgent need to assess the nutraceutical properties especially of the underutilized/wild edible vegetable crops used traditionally by the different tribes of the region with appropriate (in situ and ex situ) conservation measures.

Table 15.5 List of family and genera of mushroom from Meghalaya (contains edible as well as nonedible species)

S. no.	Family	Genus
1.	Agaricaceae	*Agaricus bisporus*, *Agaricus* sp., *Coprinus* sp., *Lycoperdon* sp., *Lepiota* sp., *Leucoagaricus* sp., *Macrolepiota* sp.
2.	Auriculariaceae	*Auricularia* sp.
3.	Dacrymycetaceae	*Calocera* sp.
4.	Agaricaceae	*Calvatia* sp.
5.	Marasmiaceae	*Campanella* sp., *Lentinula* sp., *Marasmius* sp., *Trogia* sp.
6.	Cantharellaceae	*Cantharellus* sp., *Craterellus* sp.
7.	Clavulinaceae	*Clavulina* sp.
8.	Tricholomataceae	*Collybia* sp., *Lepista* sp., *Tricholoma* sp.
9.	Inocybaceae	*Crepidotus* sp.
10.	Phallaceae	*Dictyophora* sp.
11.	Entolomateacae	*Entoloma* sp.
12.	Polyporaceae	*Favolus* sp., *Fomes* sp., *Lenzites* sp., *Lentinus* sp., *Polyporus* sp.
13.	Physalacriaceae	*Flammulina* sp., *Oudemansiella* sp.
14.	Gomphaceae	*Gomphus* sp., *Ramaria* sp.
15.	Strophariaceae	*Gymnopilus* sp.
16.	Ganodermataceae	*Ganoderma* sp.
17.	Hymenogastraceae	*Hebeloma* sp.
18.	Hygrophoraceae	*Hygrocybe* sp.
19.	Xylariaceae	*Hypoxylon* sp.
20.	Helvellaceae	*Helvella* sp.
21.	Hydnaceae	*Hydnum* sp.
22.	Cortinariaceae	*Inocybe* sp.
23.	Hydnangiaceae	*Laccaria* sp.
24.	Russulaceae	*Lactarius* sp.
25.	Fomitopsidaceae	*Laetiporus* sp.
26.	Morchellaceae	*Morchella* sp.
27.	Paxillaceae	*Paxillus* sp.
28.	Pluteaceae	*Pluteus* sp., *Volvariella* sp.
29.	Pleurotaceae	*Pleurotus* sp.
30.	Boletaceae	*Pulveroboletus* sp.
31.	Psathyrellaceae	*Psathyrella* sp.
32.	Russulaceae	*Russula* sp.
33.	Sclerodermataceae	*Scleroderma* sp.
34.	Schizophyllaceae	*Schizophyllum* sp.
35.	Suillaceae	*Suillus* sp.
36.	Lyophyllaceae	*Termitomyces* sp.

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16 Moringa for Nutrition and Entrepreneurship

T. Arumugam, E. Allirani, and V. Premalakshmi

Abstract

Moringa is one of the important crop species with its origin from sub-Himalayan tract with multipurpose uses including medicinal and nutritional benefits. Nutrients such as iron, calcium, magnesium and zinc are found to be present in Moringa leaves higher than other crops. Almost all parts of the Moringa tree are used in many ways with desirable benefits by humans. Moringa has a wide range of uses including water purification, medicine, fuel wood, forage and green manure. Among various countries in the world, maximum production and productivity are registered in India, especially in Tamil Nadu state. Moringa plant parts could be an important raw material for many agropreneurs looking for huge profits with less investment. Due to increasing demand for natural food products, organic cosmetic products and value-added products from Moringa in the international market, Moringa business ideas could increase the marketing opportunity and export of these products in various countries. This Moringa entrepreneurship and market opportunity might promote India to the top rank in agricultural exports.

Keywords

Moringa oleifera · Nutrition · Entrepreneurship · Export · Market opportunity · Value-added products

T. Arumugam (✉) · E. Allirani
Horticultural College and Research Institute (TNAU), Periyakulam, Theni District, Tamil Nadu, India
e-mail: tarumugam64@tnau.ac.in

V. Premalakshmi
KVK, Vellore, Tamil Nadu, India

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16.1 Introduction

Moringa is native to the sub-Himalayan tracts of north-west India, Pakistan, Bangladesh and Afghanistan (Foidl et al. 2001) but has been a widely grown tree around the world viz., India, Ethiopia, Pacific Islands, Florida, Sudan Caribbean, the Philippines, South Africa, Asia and Latin America and is naturalized in many locales. Arora et al. (2013) reported that there were about 33 species of Moringaceae family. *Moringa oleifera* is one of the commonly cultivated species of Moringaceae families. Among those, best known of the 13 species, namely *M. arborea, M. borziana, M. concanensis, M. drouhardii, M. hildebrandtii, M. longituba, M. oleifera, M. ovalifolia, M. peregrina, M. pygmaea, M. rivae, M. ruspoliana* and *M. stenopetala*, are well known and found worldwide. Numerous studies have reported its multipurpose use like medicinal and nutritional benefits (Anwar et al. 2007).

Moringa goes by many names. *Moringa oleifera* Lam. is popularly called the "miracle tree". In the Philippines, where the leaves of the Moringa are cooked and fed to babies, it is called "mother's best friend" and "malunggay". Other names for it include the benzolive tree (Haiti), horseradish tree (Florida), Nébéday (Senegal) and "drumstick tree" (Jahn 1991) in India. *Moringa oleifera* has a wide range of uses; among those are water purification, human consumption, medicine, fuel wood, dye, soil and water conservation, livestock forage and green manure (ECHO 2009; Melesse et al. 2011). All plant parts have a remarkable range of some functional and nutraceutical properties (Singh et al. 2012), which make this plant a diverse biomaterial for food and allied uses. According to Dawit et al. (2016), *Moringa* has multipurpose uses, is well adapted and has significant economic importance, as it has vital nutritional, industrial and medicinal applications.

The leaves, flowers and fruits of this plant are used in the preparation of several delicacies in Indian subcontinent. High nutritional value of its edible portions paves a way in making this plant more popular as an important food source in order to combat protein energy malnutrition problem that prevails in most of the underdeveloped and developing countries of the world. Presence of various types of antioxidant compounds makes this plant's leaves a valuable source of natural antioxidants (Anwar et al. 2007) and a good source of nutraceuticals and functional components as well (Makkar and Becker 1996).

The Moringa plant has been consumed by humans throughout the century in diverse culinary ways (Iqbal and Bhanger 2006). Almost all parts of the plant are used culturally for its nutritional value, for purported medicinal properties and for taste and flavour as a vegetable and seed. The leaves of *M. oleifera* can be eaten fresh or cooked or stored as a dried powder for many months reportedly without any major loss of its nutritional value (Arabshahi et al. 2007; Fahey 2005). Epidemiological studies have indicated that *M. oleifera* leaves are a good source of nutrition and exhibit anti-tumour, anti-inflammatory, anti-ulcer, anti-atherosclerotic and anticonvulsant activities (Chumark et al. 2008; DanMalam et al. 2001; Dahiru et al. 2006). The investigation of different parts of the plant is multidisciplinary, including but not limited to nutrition, ethnobotany, medicine, analytical chemistry, phytochemistry and anthropology (McBurney et al. 2004).

Numerous research reports have shown the multipurpose uses of most parts of *Moringa oleifera* in making food for human consumption such as cake by Kolawole et al. (2013); yoghurt (Kuikman and O'Connor 2015), amla (Karim et al. 2015) and weaning foods by Arise et al. (2014); bread by Chinma et al. (2014); and soups (Babayeju et al. 2014) and biscuits by Alam et al. (2014).

Common nutritional uses/benefits of different parts of *Moringa oleifera* Lam. tree

Plant parts	Nutritional uses/benefits	Phytochemistry	References
Leaves	1. *Moringa* leaves are a very rich source of vitamins A and C, calcium, potassium, protein and essential elements in comparison to other items, *viz.* carrot, orange, cow milk and banana. The leaves may be supplemented as essential food and alternative of tea leaves.	**Vitamin A 6.780 mg**—carrot: 1.890 mg Vitamin C 220 mg—orange: 30 mg **Calcium 440 mg**—cow's milk: 120 mg **Potassium 259 mg**—banana: 88 mg Protein 6.6 mg—cow's milk:	Gyekye-Asiedu et al. (2014) Anwar et al. (2007), Fozia et al. (2012) Kamal (2008) Mahmood et al. (2010),

(continued)

Plant parts	Nutritional uses/benefits	Phytochemistry	References
	The leaves can be served to check malnutrition in the poor. It is a nutraceutical and panacea for various diseases having 35 elements 2. Leaf powder used as hand-washing product—hand hygiene to reduce gastrointestinal and respiratory illness 3. Leaves' tender twigs and immature pods used as fodder for cattle to increase milk 4. Pregnant women consume leaves and flowers to increase milk for infants 5. Leaf powder used as biocontrol in crops, as fertilizers and pesticides	3.2 mg 14 macroelements and 21 microelements (total 35 elements) During hand washing, the mechanical friction by the dry leaf powder reduces the bacterial effect in comparison to nonmedicated liquid soap Having higher percentage of vitamins, essential elements and proteins Leaves having iron, minerals, vitamins and proteins	Paliwal et al. (2011b) Paliwal et al. (2011a) Parrotta (2009) UNWFP, Dec (2004) Mahmood et al. (2010), Parrotta (2009) -do- -do-
Stem	Stem pulp used in picking sticks, and newspaper making and textile industries Stem corky bark yield. Fibres used in making mats, paper, cordages, etc.	Having cellophane	Parrotta (2009)
Pods	Immature pods cooked as vegetable or pickled, having high nutritional and medicinal values	Having higher percentage of vitamins, essential elements, glycosides, etc.	Parrotta (2009)
Seeds	1. Seed powder paste used as water purifier to improve the quality of drinking water by absorbing the heavy metals, viz. cadmium, copper, chromium, lead and zinc, which are highly toxic to human being 2. The seeds can be used as nutritional supplements and for industrial and agriculture purpose. It is also being used in perfume industries, cosmetics, lubricants and for soap making. It can also be used as vegetable in daily consumption	*Moringa* is a cationic polyelectrolyte of short chain and low molecular weight Heavy metals having higher charges Seeds' oil locally known as "*ben oil*" "*Drumsticks*" similar to *olive oil* and is rich in palmitic, stearic, behenic and oleic acids. The oil is clear and odourless and resists rancidity; oil possesses 75% oleic acid	Nand et al. (2012) Ojiako and Okeke (2013)

16.2 Nutritional Value of Moringa

A prolonged and good-quality food supply is essential for the development of any stable community. People should be able to fulfil their nutritional requirements consuming vegetables, fruits, cereals, meat and milk, but many of these products are not affordable for a great number of persons, especially those who live below the poverty line. Therefore, in the communities constituted by poor or extremely poor people, plants that are particularly nutritious are valuable members of the available spectrum of plants. Moringa seems to have the potential for solving these problems in the communities and could play an important role in sustainable communities due to its high nutritious quality and adaptability to diverse and challenging environments.

It has long been cultivated, and all its parts have been consumed and used for a variety of purposes across the tropics (Jahn 1984). This is because of its impressive range of nutritional and medicinal values (Bukar et al. 2010). Oluduro (2012) reported the presence of the following minerals in leaves: sodium (11.86), potassium (25.83), calcium (98.67), magnesium (107.56), zinc (148.54), iron (103.75) and manganese (13.55) among others in parts per million and nutrients such as carbohydrate (45.43%), protein (16.15%), fat (9.68%), crude fibre (9.68%), moisture (11.76%) and ash (10.64%) (Nweze and Nwafor 2014).

The leaves are edible and are commonly cooked and eaten like spinach or used to make soups and salads. The composition of amino acids in the leaf protein is well balanced (Foidl et al. 2001; Ogbe and Affiku 2011). The leaves and pods are helpful in increasing breast milk in nursing mothers during breastfeeding (Oluduro 2012).

High protein content is one of the most cited advantages of Moringa leaves. For example, they contain nine times more protein than yoghurt (Mathur 2006). In various reports (Chandan 2006), it has been reported that cow, buffalo, goat and sheep milks provide average CP contents of 3.4%, 4.7%, 4.1% and 6.3%, respectively, while fresh and dry Moringa leaves exhibit CP contents of 67.0 and 271.0 g kg^{-1} respectively. These comparisons confirm that Moringa leaves contain higher amounts of CP in comparison with milk. Moringa leaves are a rich protein source (Thurber and Fahey 2009); they can be used by physicians, nutritionists and members of the health community to solve the malnutrition problem. One tablespoon of Moringa leaf powder contains 9.9–13.6% of the daily CP requirement of children and breastfeeding mothers. It has also been reported that the amino acid profile of Moringa leaves meets the standards of the World Health Organization (WHO). Moringa leaves have higher amounts of all amino acids than are required for children; it is also reported that plant foods, especially cereal crops, have low lysine contents, while legumes show higher amounts. Moreover, it is also reported that better lysine contents are being provided by livestock products, like milk. Moringa is also a very good source of all amino acids, including lysine. Moringa seed meal also has good amounts of all the amino acids, except for valine, lysine and threonine (Oliveira et al. 1999), and also has 43.6 g kg^{-1} of protein of methionine + cysteine, which is very close to that of human milk, chicken eggs and cow milk. The seeds have been found to contain a non-toxic natural polypeptide that sediments mineral

Table 16.1 Nutritional value of *Moringa oleifera*

Component analysed	Pods	Leaves	Leaf powder
Moisture (%)	86.9	75.0	7.5
Calories	26	92	205
Protein (g)	2.5	6.7	27.1
Fat (g)	0.1	1.7	2.3
Carbohydrate (g)	3.7	13.4	38.2
Fibre (g)	4.8	0.9	19.2
Minerals (g)	2.0	2.3	–
Ca (mg)	30	440	2003
Mg (mg)	24	24	368
P (mg)	110	70	204
K (mg)	259	259	1324
Cu (mg)	3.1	1.1	0.57
Fe (mg)	5.3	7	28.2
S (mg)	137	137	870
Oxalic acid (mg)	10	101	1600
Vitamin A—B-carotene (mg)[a]	0.11	6.8	16.3
Vitamin B—choline (mg)	423	423	–
Vitamin B_1—thiamine (mg)	0.05	0.21	2.64
Vitamin B_2—riboflavin (mg)	0.07	0.05	20.5
Vitamin B_3—nicotinic acid (mg)	0.2	0.8	8.2
Vitamin C—ascorbic acid (mg)	120	220	17.3
Vitamin E—tocopherol acetate (mg)	–	–	113
Arginine (mg)	90	402	1325
Histidine (mg)	27.5	141	613
Lysine (mg)	37.5	288	1325
Tryptophan (mg)	20	127	425
Phenylalanine (mg)	108	429	1388
Methionine (mg)	35	134	350
Threonine (mg)	98	328	1188
Leucine (mg)	163	623	1950
Isoleucine (mg)	110	422	825
Valine (mg)	135	476	1063

[a] Moringa pods, fresh (raw) leaves and dried leaf powder have shown to contain the following per 100 g of edible protein (Choudhary et al. 2016)

particles and organics in the purification of drinking water, cleans vegetable oil and sediments fibres in the juice and beer industries (Muyibi and Evison 1995; Ndabigengesere et al. 1995).

Moreover, Moringa dry leaves and fresh pods are also a good source of amino acids (Table 16.1). Arginine, valine and leucine contents were found higher in Moringa dry leaves and fresh pods, while serine, glutamate, aspartate, proline, glycine and alanine could not be detected in these Moringa parts (CSIR 1962).

The nutritional characteristics of the Moringa tree are excellent; hence, it can easily be used as a fresh forage material for cattle. The leaves are rich in protein, carotene, iron and ascorbic acid, and the pod is rich in the amino acid lysine (CSIR 1962). Nutritional analysis indicates that Moringa leaves contain a wealth of essential disease-preventing nutrients, which makes it suitable to be included in diets as food supplement (Krishnaiah et al. 2009). Moringa leaves have been used to combat malnutrition, especially among infants and nursing mothers, and hasten uterine contraction during childbirth in pregnant women (Oluduro 2012). It has also been found that the extract obtained from the leaves of Moringa in 80% ethanol contains growth-enhancing principles for higher plants (Makkar and Becker 1996).

16.3 Chemical Constituents

The protein content of fresh leaves does not vary substantially from place to place (Table 16.1).

16.4 Health Benefits of *Moringa*

There are many uses of *Moringa*, viz. medicines, human food, water purification, animal fodder, alley cropping, fertilizer, live fence, domestic cleaning agent, fuel wood and other uses. *Moringa* has increased physical energy—it tunes the body up with naturally occurring nutrients to make your energy last longer. Numerous research reports reveal that parts of *Moringa* plant can be used in different ways. The uses of *Moringa oleifera* are well documented by Fahey (2005), as nutritional, industrial, medicinal and agricultural advantage.

Moringa oleifera has great potential for the prevention of different diseases like nutrient deficiency, cancer and anaemia as well as for dirty water purification. *Moringa* powder contains sufficient amount of vitamins, minerals, protein, phenols and other phytonutrients. This makes the tree a medicine for many different diseases (Gedefaw 2015). *Moringa oleifera* is also promoted by the World Health Organization (WHO) as an alternative to imported food source to treat malnutrition (Sreelatha and Padma 2009).

16.5 Moringa Production in India

In India, *Moringa oleifera* is widely cultivated for its multiple benefits and varieties are released by the agricultural universities in Moringa and are occupying the daily meals of the citizens of different nations. In this respect, understanding the nutritional value of Moringa will be an important one so as to develop value-added products from Moringa.

India is the prime producer of Moringa (drumstick) with an annual production of 2.2 million tonnes of tender fruits from an area of 43,600 ha leading to the productivity of around 51 tonnes per ha. Among the different states, Andhra Pradesh leads in both area and production (15,665 ha) followed by Tamil Nadu (13,042 ha) and Karnataka (10,280 ha). In other states, it occupies an area of 4613 ha. Tamil Nadu is the pioneering state as it has varied genotypes from diversified geographical areas, as well as introductions from Sri Lanka.

In Tamil Nadu, Moringa was cultivated as a sole crop in homesteads, around cattle sheds, on farm boundaries and as isolated plants in fences and as groups of trees on village wastelands. In the early 1990s, in Southern Tamil Nadu, people started growing perennial Moringa types. In Mulanur block of Dharapuram taluk, Moringa was established as an intercrop on field in a large scale and their allies were cropped with vegetables and Sorghum formed a Moringa-based intercropping system. This Moringa-based cropping system was evolved as a protection to alley crops from drying winds during summer, and Moringa also provided some additional income. With the migration of people from South to North India, and elsewhere in the world, the Moringa cultivation and the demand for Moringa have picked up.

Farmers found that growing Moringa crops during summer season was remunerative. Thus, Moringa gained a foothold as a summer vegetable. Its unique flavour and aroma became very popular. For a South Indian, any meal without Moringa and pulses is considered as incomplete. The demand for Moringa pod also increased due to increased urban settlements and migration of people to urban colonies. Based on the significance of Moringa in the human diet, a research study might be more viable focusing marketing, value addition and export practices of Moringa in Tamil Nadu.

Tamil Nadu is one of the largest producers of Moringa with an annual production of 6.71 lakh tonnes of tender fruits from an area of 13,042 ha. Among the districts, Theni leads in both area and production (3424 ha) followed by Dindigul (2645 ha), Karur (2070 ha), Thoothukudi (1465 ha), Tiruppur (1191 ha), Ariyalur (813 ha) and Madurai (536 ha). The area under Moringa is skewed to certain districts because of good soil conditions and becomes good revenue earner among the rural households, and hence Moringa cultivation in these districts becomes a popular one.

In Tiruppur district, the Mulanur block had the highest area under Moringa next to Sathankulam of Thoothukudi district. Sathankulam had become the hub of Moringa cultivation (Sekhar et al. 2018).

16.6 Moringa for Entrepreneurship

Moringa is a gold mine for an agropreneur looking for an area to invest in agribusiness good profit with low investment cost. This business gives quick return in the same year of investment. There are many investment opportunities in Moringa business. Prospective investors can invest in Moringa seedling production, Moringa plantation (for either leaves or pods or seed production), Moringa processing, Moringa-based feed production, Moringa based health products, cosmetics, and export, etc. Moringa products are Moringa powder, Moringa capsule, Moringa tablet, Moringa oil, Moringa beverages (tea), Moringa chocolate, Moringa hormone, Moringa soap, Moringa lotion, etc.

The export market for Moringa is increasing at over 30% rate; Moringa products, most especially the seeds and leaves, have been exported to the USA, the UK, China and African countries. It is important to know that there are standards for regulating Moringa products' export. Leaf-exporting companies are now making a shift towards organic leaves and usage of solar dryer. Moringa leaves have applications in nutraceutical, pharmaceutical and cosmetics industries. Solar drying is superior to open sun-drying because of the better quality, colour and hygiene. Hence, it is necessary to dry the leaves in a controlled manner.

16.7 Value Addition in Moringa

There is an important place for Moringa in terms of value addition process. Moringa available in our country has more market opportunity abroad than within. Most of us could have known only about powdering Moringa and selling it. But many are not aware that Moringa has a huge international market to an extent of separating all its parts including its seeds.

Through value addition process, all the parts of Moringa, such as its bark, leaves and seeds, can be sold. There are so many varieties of products from Moringa that could be gained through value addition, starting from Moringa powder to Moringa tea mix, Moringa strawberry mix, Moringa peppermint, Moringa bark oil, seed oil, leaf oil, Moringa dhal, Moringa oil cake, Moringa shampoo, Moringa soap, Moringa face cream and Moringa soup mix.

16.8 Moringa Leaf Powder

Moringa powder is packaged and branded. The end user can use it in food and soups as a supplement or put it in hot water and drink directly. Drying and packaging of Moringa leaves into powder should be done in hygienic conditions. This is to ensure that the end product is pure and has no contamination. In good storage conditions, Moringa powder has a shelf life of 180 days (6 months).

16.9 Moringa Leaf Tablets and Moringa Capsules

Moringa powder can be made into tablets and capsules. This is for direct intake as a supplement.

16.10 Moringa Oil

Moringa oil, also known as ben oil, is extracted by either cold pressing or solvent extraction. Moringa oil is known to have antioxidant, antimicrobial, anti-inflammatory, disinfectant, anti-ageing, skin-moisturizing and exfoliating properties. The oil is usually extracted from the seeds.

16.10.1 Moringa-Flavoured Tea

Moringa can be flavoured and packaged into teabags for intake. Common flavours are strawberry- and peppermint-flavoured teabags. You can consider including some tea (chai) in the blend or just pure Moringa with the peppermint or strawberry blend.

16.10.2 Energy Bars

Moringa energy bars are snacks on the go that contain high nutritious food, mostly nuts, cereals and supplements. The target market for Moringa energy bars is busy people who might not have time for a nutritious meal. A growing target market is children, as they serve as alternative snacks. The energy bars can be sweetened with jaggery or honey as alternative sweeteners for sugar. Moringa energy bars can be stored well for 8 months.

16.10.3 Moringa Wonder Mix

Moringa powder, mixed with nutmeg, cashew, cardamom and dry ginger, has been helpful in general well-being and vitality. This mixture is based on ancient ayurvedic practices. Moringa wonder mix is widely used as a natural chemical-free aphrodisiac.

16.10.4 Moringa Gum Powder

Moringa gum powder has diuretic and astringent properties. It has been known to help with fever, dysentery, asthma and intestinal cancer.

16.10.5 Moringa Instant Soups and Moringa Instant Shakes

Moringa can be mixed with other soup and shakes ingredients to create highly nutritious powders that can be turned into soup or shakes instantly.

16.10.6 Moringa Honey

The Moringa farmer can place beehives in their Moringa plantation. Honey produced by bees that get nectar from Moringa flowers is known to have medicinal properties that are associated with Moringa.

16.10.7 Moringa Dry Flowers

Dried Moringa flowers are taken in hot/cold tea or used in salads and soups.

16.10.8 Moringa Bio-Booster

Moringa, mixed with other natural extracts, can be used as a natural foliar spray to boost the growth of other plants.

16.10.9 Moringa Seed Cake

Moringa seed cake, also known as Moringa oil cake, is a by-product of oil extraction from Moringa seeds. It is used as an organic fertilizer and as a natural water purification agent. Moringa seed cake is rich in potassium, magnesium, calcium, phosphorus, nitrogen, copper, iron, manganese, zinc and nickel. This helps improve soil fertility when used as a fertilizer.

16.11 Major Export Products from Moringa

- Moringa leaf powder
- Moringa oil

16.12 Moringa Leaf Powder

Moringa leaf powder is used as a dietary supplement and falls under the market category of herbs and botanicals like green superfoods such as spirulina, wheatgrass and barley grass. The market for nutraceutical supplements has rapidly increased over the past decade.

The main markets for dietary supplements are the USA, followed by Western Europe and Japan, all with an affluent middle class willing to invest in alternative health and food products. The USA dominates the overall market in nutritional supplements, and Europe accounts for the largest share of the world market in herbal/botanical supplements and remedies. Asia Pacific and Japan make up the other important market for botanicals, with the Asia Pacific market (led largely by China and India) set to pave the way with the highest growth rate (10.5%) through 2017 (Global Industry Analysts, Inc., 2013). Judging by the increasing number of products available on the international market, it seems safe to say that the demand for Moringa leaf powder products is growing.

In the USA, Moringa is increasingly becoming available in health shops, both online and offline. The leaf powder has been sold for a few years already, and products like health bars and dietary supplement are used in teas or energy drinks. They are marketed as caffeine-free energy boosters and as a superfood, with a composition comparable to spirulina. Under the EU regulation, only the whole or powdered leaves of Moringa are allowed to be imported as food.

16.13 India Dominates the Current Global Market and Meets More Than 80% of Global Demand

A large percentage of global Moringa production is taking place in India is largely due to the long tradition of including Moringa in its food consumption. As a result, Indian Moringa is grown on large plantations, making it possible for Indian wholesalers to sell Moringa leaf powder at a comparatively low price (and most of the time online). Many companies are coming up with claims that their Moringa leaf powder is, as a result, of a higher quality, while also providing a story that Western consumers consider important. Moringa leaves need to be dried immediately upon harvesting, and the cost of transporting loose dried leaves is high, which means that EU buyers are dependent on countries that produce Moringa in powdered form in order to meet their demands. Indian wholesalers offer Moringa leaf powder at a comparatively low price. Pricing of Moringa leaf powder in the international market depends on quantity, quality and end use of the product. Wholesale prices for Indian Moringa leaf powder (the product sold on the largest scale) range from US$ 2.26 to 7.90/lb, with an average price of US$ 2.97/lb (source: ZAUBA.com).

16.14 Moringa Oil

Exotic plant-based oils like Moringa often have specific active and functional properties, making them particularly valuable for use in cosmetic products. Following health and wellness trends, Western consumers increasingly prefer cosmetics with ingredients derived from plants, rather than mineral oil. This trend to consume "truly natural" cosmetic products is in line with other patterns in the Eastern society, where consumers increasingly adopt green values and seek out companies that accept responsibility for social issues and the environment. In response to these trends, the cosmetic industry has begun to differentiate its products by using more exotic vegetable oils, in turn triggering a growing international demand (and thus higher prices) for oils derived from sources like Moringa.

16.15 Market Opportunity

Other than Tamil Nadu, the products of Moringa are sold in other states of India as well. The value-added Moringa products are used abroad for their medicinal properties. It is also used as a daily food product in Malaysia, Singapore and Japan. There are many countries awaiting the good-quality Moringa products to be imported from India. What they need is organically grown natural products. They tend to reject products that are made using chemical inputs as they love naturally grown products. This will further lead to loss of market opportunity as well.

Moringa products such as powders, oils, capsules, pills, soaps and seeds are obtained from different parts of the Moringa tree. The global Moringa product market was projected to expand at a considerable rate over the last few years owing to the health benefits associated with the products derived from the tree.

Rising awareness among the consumers regarding the benefits of Moringa has resulted in increased demand for Moringa products in end-use industries. Moringa is used in industries such as functional food and beverages, pharmaceuticals, nutraceuticals and personal care. Functional food and beverage is the fastest growing segment of the Moringa product market.

Increasing Demand for Food Supplements Owing to Rising Awareness About

- Nutrition
- Growing geriatric population
- Hectic lifestyle
- Rising disposable income

Shall foster the Moringa ingredients' market growth. Growing awareness regarding the medicinal benefits of Moringa-based products is projected to propel industry growth.

Moringa flowers, seeds, pods, leaves, gum and bark have properties to relieve vitamin and mineral deficiencies; promote normal blood glucose levels; provide support for a healthy cardiovascular system, body's anti-inflammatory mechanisms and immune system; neutralize free radicals; and enrich anaemic blood. They have potential benefits with regard to malnutrition, lactating mothers, general weakness, depression, menopause, osteoporosis and arthritis. Growing incidence of obesity and increasing preference of individuals towards fast food products are the key factors augmenting the dietary supplement market demand. Global dietary supplement market surpassed USD 125 billion in 2018.

In dietary supplements, Moringa is used as an ingredient due to the presence of a large number of essential nutrients that help in improving health. Rising consumer awareness and dietary supplement consumption in the USA, Canada, India, China, the UK, Germany and Australia are the key contributing factors towards market growth.

Global cosmetics market size may grow significantly at around 5.5% during the forecast time frame owing to growing consumer demand for hair and skin lotions. Shift in consumers' preference towards herbal cosmetic products may in turn accelerate the overall market demand.

Increasing demand for wheat-based products is projected to hamper Moringa ingredient market profitability. Also, stringent government regulations regarding the export of Moringa may hinder the market growth. Organic certification is important before using it for nutritional supplement purpose, which may drive the market share.

16.16 Market Potential in Moringa

North America: Increasing demand for dietary supplements

Europe: Growing demand for health/organic products

Asia Pacific:

Growing demand for plant-based cosmetic products and Moringa tea market size from online distribution channel may register gains close to 7.5% during the forecast time period. Growing per capita disposable income along with increasing penetration of online purchase in the USA, India, China, Germany and the UK may contribute towards segment growth.

In North America, driven by Canada, Mexico and the USA, Moringa ingredient market demand should surpass USD 5 billion by 2025 due to the growing demand for plant-based supplements. Increasing demand for natural cosmetic products in the USA and Canada may augment regional growth. Increasing demand for organic health supplements as they are used to reduce weight and calorie reduction may support regional growth.

European Moringa ingredient market demand driven by Germany, France, the UK and Italy may exceed USD 2 billion up to 2025. Increasing demand for food supplements to prevent diseases may support regional industry growth. There is a growing demand for Moringa tea in the region as it promotes weight loss, provides nourishment, helps in food digestion and improves skin health.

Asia Pacific, led by India, Japan and China, market size may grow significantly at around 8% during the forecast time period. Rising awareness among individuals regarding nutritional enrichment may accelerate regional growth demand. Increasing number of brand campaigns on electronic media to create product awareness among individuals by major manufacturers should favour market growth.

16.16.1 China and Kenya

China-aided Moringa project has boosted the fortunes of Kenyan smallholders. Collaborative research involving Chinese and Kenyan scientists has revived cultivation of Moringa and other indigenous plants. Chinese Moringa leaf powder market demand for food application exceeded USD 30 million in 2018. Increasing demand for natural food ingredients owing to rising health awareness should stimulate the regional market.

16.16.2 The Philippines

In the Philippines, almost all parts of the plant are used for food and traditional medicine. More new Moringa-based products are being developed by more than 20 food and cosmetic industries in the Philippines. In spite of the growing Moringa industry, there is a shortage of good-quality fresh and dry Moringa raw materials. The supply of Moringa powder is inadequate and unstable and can be attributed to a scarcity of seed and planting materials. There is no stable and commercial Moringa oil industry due to limited seed supply.

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Mushrooms for Nutrition and Entrepreneurship

17

Manjit Singh

Abstract

Mushrooms can be used as food, dietary supplements and medicine. Mushrooms are a rich source of protein having essential amino acids and high digestibility. Mushrooms have all the nine essential amino acids required by human being. Mushrooms are good for heart as they have got low fat, no cholesterol and more of unsaturated fatty acids, and some of the mushrooms have compounds like lovastatin that is known to lower the cholesterol in the blood. Moreover, mushrooms have low sodium and high potassium content, making it a suitable food for persons suffering from high blood pressure. Mushrooms are also considered a delight of diabetics as it is a low-calorie food with no starch and has also a number of antioxidants. These are also a very good source of vitamins, especially vitamin B complex. Mushrooms are the vegetarian source of vitamin D, the quantity of which can be enhanced tremendously by exposing mushrooms to UV light. These are also rich in minerals, which also include copper (heart protective) and selenium (anti-cancer). Mushrooms are low-calorie, fat-free, cholesterol-free and gluten-free food. These are rich in fibre and hence good for weight management and bowel management. Many of the mushrooms are known to have antiviral properties, and their consumption activates the immune system of the human body. Beta-glucans and a number of other compounds from different mushrooms have found applications in cancer research, and a number of them have been found to reduce the side effects of radiotherapy and chemotherapy. Mushroom as a vocation does not mean just cultivation. It has various components like spawn production, compost production, cultivation, canning, processing and marketing, each one of which is an entrepreneurial activity suitable for youth and women.

M. Singh (✉)
ICAR-Directorate of Mushroom Research, Solan, Himachal Pradesh, India

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Keywords

Mushroom · *Agaricus* · Nutritive value · Cultivation

17.1 Introduction

17.1.1 Global Population vs. Quality Food, Health, and Environment

The three problems facing the human race are quality food, health and environment. The magnitude of these problems is set to increase as the world's population continues to grow. The dwindling natural resources are constraining the production systems, and these constraints are going to increase with increase in population, changing lifestyles and various degradative processes already affecting the globe. The public is increasingly curious about where and how their food is produced and what impact it has on the environment. There is increased acceptance that plant-based choices are beneficial not only for health but also for the environment. One of these is mushrooms.

Humans have been collecting and consuming mushrooms since ages, but their cultivation is a recent development. Mushrooms are members of the fungi kingdom. All mushrooms are fungi, but all fungi are not mushroom. Unlike higher plants, mushrooms do not have chlorophyll which helps plants to use water and carbon dioxide from earth and energy from the sun to make their own food. These have cell wall as in plants, but the composition of fungal cell wall is different. As mushrooms cannot produce their own food, these depend on higher plants for food. Mushrooms obtain nutrients from organic materials like straw, dead wood, manure and dung. Mushrooms were earlier considered as plants. Now these are classified as a separate kingdom (Fig.17.1). That is, these are neither plants nor animals. All of us eat lot of fungi while taking fermented foods like cheese and bread. Mushroom is another prized fungus used as vegetable.

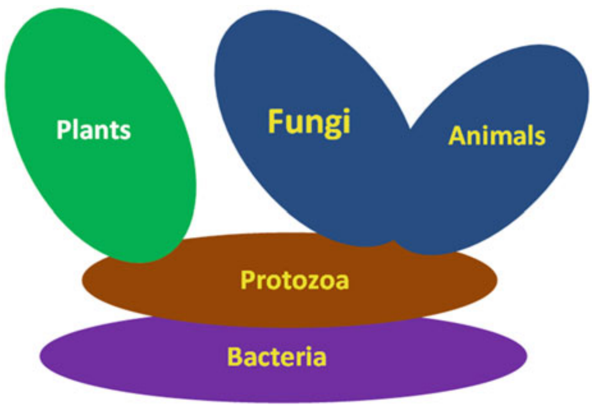

Fig. 17.1 Five kingdoms of organisms on earth

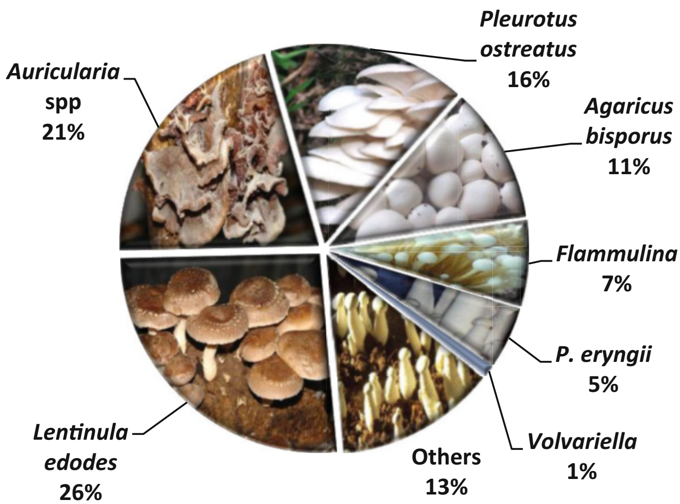

Fig. 17.2 Relative contribution of different species in 43 MT world production in 2018–2019

Consumption of mushrooms, however, is not so common in our country. Commercial cultivation of mushrooms in the world picked up only after World War II (Singh et al. 2017). In 1960s, button mushroom was the most commonly available cultivated mushroom. Over time, a number of other mushrooms have been cultivated, and contribution of different mushroom species to the world mushroom production has been changing with time (Singh et al. 2018). World production has increased to 43 million tons in 2018–2019 (Singh et al. 2020, 2021; Fig. 17.2) and may surpass 50 MT by 2025. Mushroom cultivation in India has started picking up, and there has been exponential growth in the last decade (Sharma et al. 2017, 2021). Despite this, as compared to the world mushroom production of over 43 MT, our current production (2020–21) of 0.24 MT (Fig. 17.3) accounts for about 0.5% of global mushroom production.

We have finite resources and land mass, and global population is likely to continue to increase. Population of India may surpass that of China in 2030 (Guilmoto and Gavin Jones 2016). The current global population of over seven billion is likely to be more than nine billion by 2050. Global population growth may be a bigger threat than climate change. In fact, the latter is the outcome of this growth. Scientists have been making efforts to meet the demands of food of this increasing population. Genetic improvement along with other technological interventions has helped the human race to produce enough food to the exponentially increasing population. According to some estimates, genetic improvement in cereals from 1961 to 2019 has spared 1.48 billion ha of land, implying that in the absence of it, we would have required this much additional land to produce what we are producing today if global average cereal yields had not increased since 1961 (https://ourworldindata.org/grapher/cereal-land-spared). Actual cropland area used in 2019 for cereals was 724.26 million ha and land spared due to crop yield

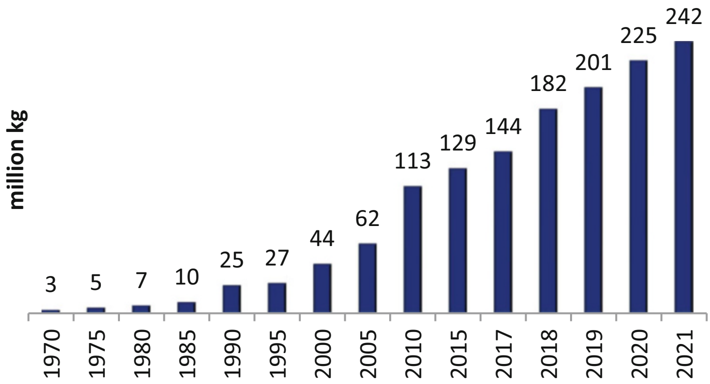

Fig. 17.3 Mushroom production in India

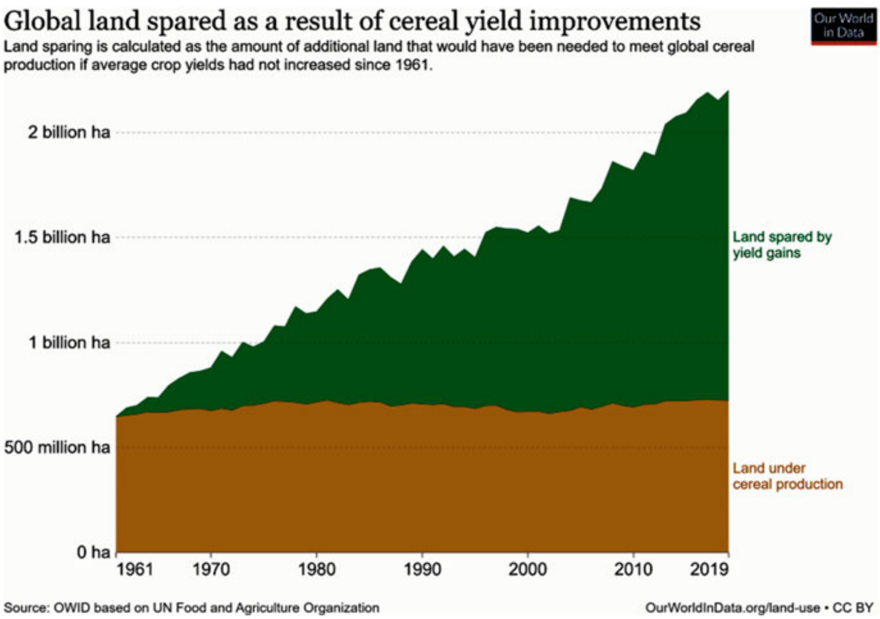

Fig. 17.4 Land spared due to genetic improvement in cereals. (https://ourworldindata.org/grapher/cereal-land-spared)

improvements was 1480 million ha (Fig. 17.4). There are limits to increasing productivity. There are limits to horizontal expansion too. Thus, we need to fix our food systems and look for alternate sources of food and explore the use of three-dimensional space.

With increase in food production, there is also increase in agro-wastes. Managing agro-wastes is another challenge. As agro-wastes are storehouse of solar energy

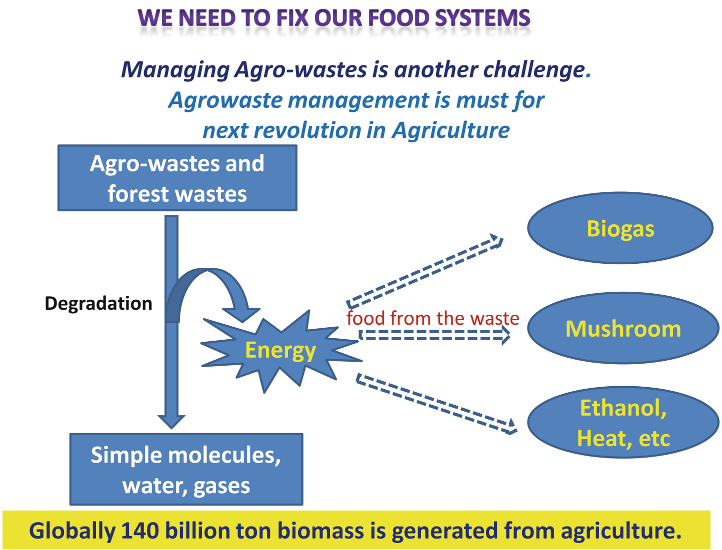

Fig. 17.5 Recycling of agro-wastes

converted to chemical energy, these are potential source of food and fuel. Agro-waste management is thus a must for the next revolution in agriculture. According to an estimate, globally 140 billion tons of biomass is generated from agriculture, forestry, etc. (https://wedocs.unep.org/20.500.11822/7614). It gets degraded in nature releasing energy in the process. For our survival on planet earth, we will have to find ways and means to make use of this energy. Next revolution will depend on our ability to effectively recycle these agro-wastes and harvest this energy for our use as food and fuel. We can use these to produce biogas, bioethanol and heat or use it for making compost or as fodder. One of the novel ways is to use it for growing mushroom (Fig. 17.5). By doing so, we produce food from the waste and also completely recycle the agro-wastes as the material left after growing mushroom is recycled into fields as compost.

With the rapid socio-economic changes and globalization, people demand quality food having nutraceutical values. In India and other developing countries, protein deficiency is an important issue that needs to be tackled. Mushrooms not only are a source of quality protein with high digestibility, but also have a number of other medicinal benefits. And on top of it, these use various straws which are burnt in many parts of our country that creates environmental problems. Mushrooms are considered to be the highest producer of protein per unit area and time. Water requirement for mushroom cultivation is far less (20 litre/kg fresh mushrooms) than field crops as they are cultivated indoors. We here discuss the nutritional composition, benefit of mushrooms and scope of their cultivation.

17.2 Nutritional Composition

Knowledge of nutritive value of any food item increases its consumption and helps formulate balanced diets, correct inadequacies through judicious use of available foodstuffs and plan agricultural policies. It is now fully recognized that mushrooms are highly nutritive and a good source of good-quality protein, vitamins and minerals. Average Indian diet is primarily cereal based and abundant in calories, but it is highly deficient in protein. Cereals are deficient in two essential amino acids, namely lysine and tryptophan; mushrooms are very rich in lysine and tryptophan and can effectively supplement cereals in our diet. Mushrooms fit in very well in the diet of predominantly vegetarian population of our country for bridging the protein gap (Rai 1986). A brief description of various components is as below.

General Composition of Mushrooms Mushrooms have high water content, and the moisture can vary from 70% to over 90%. Thus, dry matter of mushrooms is very low. There are variations in the carbohydrate, protein and fat content in different mushrooms. All are a good source of quality proteins and are low in fat. In general, on dry weight basis, the carbohydrate content may be around 50–75%, proteins 20–35%, fat 2–4% and ash around 7%. Composition has been reviewed by various workers, and there are wide variations between and within species (Ulziijargal and Mau 2011; Chang and Wasser 2012; Kalac 2013; Valverde et al. 2015). Chang and Wasser (2012) have reported ranges based on different reports in three common mushrooms (Table 17.1).

17.2.1 Proteins

Mushrooms contain a small amount of protein, about 2–3 g per 100 g fresh weight, but the types of protein are unique (Xu et al. 2011). Mushrooms have been recognized as a prominent source of quality protein. These proteins have all nine essential amino acids (Fig. 17.6). Content in *A. bisporus*, *L. edodes* and *Pleurotus* spp. varies by 10% (Chang and Wasser 2012). The mushroom proteins have high

Table 17.1 Proximate composition of the three mushroom species (based on Chang and Wasser 2012)

Proximate composition	*Agaricus bisporus*	*Lentinus edodes*	*Pleurotus* spp.
Moisture	78.3–90.5	90.0–91.8	73.7–90.8
Crude protein	23.9–34.8	13.4–17.5	10.5–30.4
Crude fat	1.7–8.0	4.9–8.0	1.6–2.2
Total carbohydrate	51.3–63.5	67.5–78.0	57.6–81.8
Ash	7.7–12.0	3.7–7.0	6.1–9.8
Energy value	328–368	387–392	345–367

All data are presented as percentage of dry weight, except moisture (percentage of fresh weight) and energy value (kcal per 100 g dry weight)
Nutritional energy = 4 × (protein + carbohydrate) + 9 × fat in fresh weight

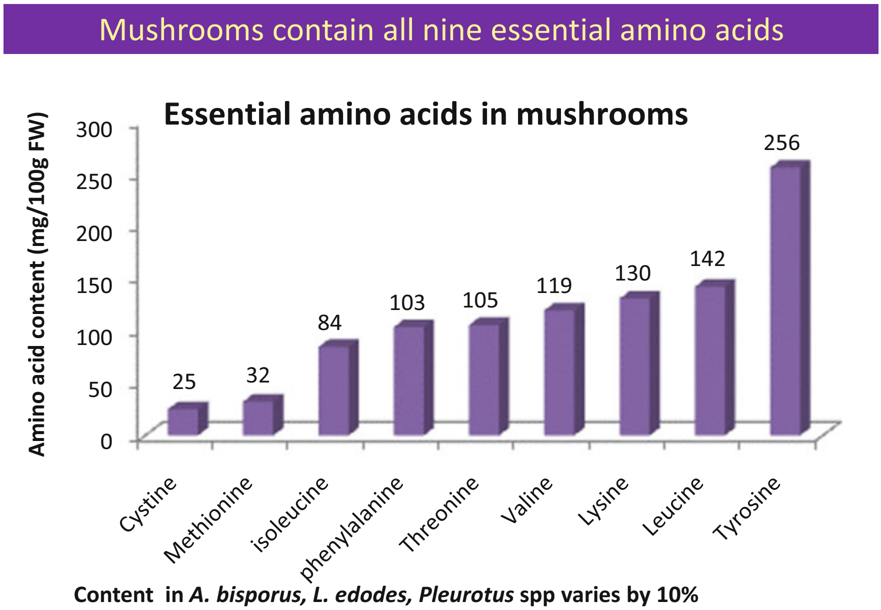

Fig. 17.6 Essential amino acids in mushrooms. (Based on Chang and Wasser 2012)

biological value, that is, high digestibility, and are good for infants, children, and pregnant and lactating women. Mushrooms also contain hydrophobins (Wu et al. 2017), which are a large family of small cysteine-rich proteins known for their ability to assemble spontaneously into amphipathic monolayers at hydrophobic–hydrophilic interfaces (the name hydrophobin was originally used due to their high content of hydrophobic amino acids) (Armenante 2008). Hydrophobins contribute to the texture of the mushroom (Bayry et al. 2012). This protein along with the natural glutamates and other natural flavour compounds makes mushroom's texture and flavour so unique (Feeney et al. 2014). Mushrooms have approximately two times more protein than in vegetables and four times protein than in fruits. Considering that a number of people suffer from malnutrition, mushrooms can be an important way to combat this problem.

Bioactive proteins are an important part of functional components in mushrooms and also have great value for their pharmaceutical potential. Mushrooms produce a large number of proteins and peptides with interesting biological activities such as lectins, fungal immunomodulatory proteins, ribosome-inactivating proteins, antimicrobial proteins, ribonucleases and laccases (Xu et al. 2011).

Some papers reported crude protein contents determined by the Kjeldahl method using the usual conversion factor of 6.25. However, such values are overestimated due to high proportion of non-protein nitrogen, particularly in chitin. A factor of 4.38 has been mostly used in recent publications (Kalac 2013).

17.2.2 Fats

Contents of total lipids (crude fat) are low, ranging mostly between 20 and 30 g/kg DM. There is thus virtually no fat in mushrooms, and whatsoever there is, it is found in the cell wall, so mushrooms can store fat-soluble vitamin D (Cardwell et al. 2018). Eighty percent of the fatty acids in edible mushrooms are unsaturated (Chang and Wasser 2012). Mushrooms are good for heart as they have got low fat, no cholesterol and more of unsaturated fatty acids, and some of the mushrooms have compounds like lovastatin that is known to lower the cholesterol in the blood. Moreover, mushrooms have low sodium and high potassium content, making it a suitable food for persons suffering from high blood pressure. The major sterol produced by edible mushrooms is ergosterol.

17.2.3 Carbohydrates and Fibre

Carbohydrates are normally classified as simple and complex carbohydrates. Simple carbohydrates are simple sugars having one or two saccharide units. They raise blood glucose levels quickly. Complex carbohydrates, also known as polysaccharides, have long chains of saccharides or their derivatives and take longer to break down. Mushrooms do not have starch and cellulose as found in plants but instead contain glycogen and chitin, the polysaccharides occurring in animals. On the other hand, the cell wall, like plants, is a characteristic structure of fungi and is composed mainly of chitin, α- and β-linked glucans, glycoproteins and pigments (melanin) (Gow et al. 2017).

Even though carbohydrates constitute more than half of the dry matter, most of these occur in the form of complex carbohydrates. The group comprises various compounds: sugars (monosaccharides, their derivatives like mannitol and oligosaccharides like trehalose), reserve polysaccharides like glycogen, construction polysaccharides like glucans and chitin, etc.

The amount of simple sugars is very small. The quantity of glucose and fructose is negligible, and even mannitol and trehalose are on average 28.9 and 39.2 g/kg DM, respectively (Kalac 2013). Mannitol is an osmoregulator and participates in volume growth and firmness of fruiting bodies. Its digestibility for humans is low. As per Tsai et al. (2007), *Agaricus bisporus* had 62.2% carbohydrates of which 13.9% were reducing sugar and 48.3% were dietary fibre (27.9 soluble polysaccharides + 20.4 insoluble fibre). Fat% was 2.5, protein% was 26.5, ash% was 8.8 and energy was 184.4 kcal/100 g.

Dietary fibres are of soluble and insoluble types. Beta-glucans found in fungi are a type of soluble fibre. Different polysaccharides have been isolated from mushrooms, most of them consisting of β-linked glucans, such as lentinan from *Lentinus edodes*, pleuran from *Pleurotus* species, schizophyllan from *Schizophyllum commune* and calocyban from *Calocybe indica*. Extensive research has been focused on beta-glucans (soluble fibre) possessing numerous positive health effects. These constituents (lentinan, pleuran, etc.) of mushroom cell walls have been investigated particularly in cultivated species and have been used in East Asian medicine. Limited data on dietary fibre have been reviewed by Kalac (2009). Contents are about 40–90 and 220–300 g/kg DM for soluble and insoluble fibre, respectively.

Chitin, an insoluble fibre, is a naturally occurring biopolymer found in fungal cell walls and exoskeleton of insects and others and is made up of amino sugars. It is a modified carbohydrate (polysaccharide) and contains nitrogen. It is normally a linear polymer of *N*-acetyl-D-glucosamine monomer, which like cellulose is linked by beta-1–4-glycosidic bonds. After cellulose, it is the next most plentiful biopolymer. Chitin's fibre provides prebiotic properties to the gut flora. This means that it aids in the growth of good bacteria in the body. Nitschke et al. (2011) reported a mean chitin content of 46.9 and 98.6 g/kg DM in *A. bisporus* and *F. velutipes*, respectively. Chitin is indigestible for humans and apparently decreases the digestibility of other mushroom components. The relatively high content of particularly insoluble fibre seems to be a nutritional advantage (Kalac 2013).

Glycogen, which is a multibranched polysaccharide of glucose, is a reserve polysaccharide of mushrooms. Limited literature data report the contents of 50–100 g/kg DM. Mushrooms due to the above type of carbohydrates mean that mushrooms may have little effect on blood glucose levels, which could make them a good food choice for people with diabetes (Khatun et al. 2007; Sang-Chul et al. 2010).

17.2.4 Vitamins

Mushrooms are a source of B vitamins, including riboflavin, niacin and pantothenic acid (Table 17.2). These B vitamins help to provide energy by breaking down proteins, fats and carbohydrates. There are variations within and between species and reports by various workers. For B group vitamins, contents of 1.7–6.3, 2.6–9.0, 1.4–5.6 and 63.8–83.7 mg/kg of thiamine, riboflavin, pyridoxine and niacin,

Table 17.2 B vitamins and minerals in mushroom (https://australianmushrooms.com.au/health)

Nutrient	Unit	Amount/ 100 g	Position	Levels in common vegetables
Riboflavin (B2)	mg	0.37	#1	Parsley 0.33, spinach 0.2
Niacin equivalent (B3)	mg	3.7	#1	Green peas 3.4, parsley 1.5
Pantothenic acid	mg	1.15	#1	Avocado 0.9, broccoli 0.5
Ergothioneine	mg	1.6	#1	Found in chicken liver, wheat germ
Biotin	μg	8.9	#2	Broccoli 9.8, cauliflower 5.7
Selenium	μg	15.4	#1	Celery 1.8, sweet corn 1.3
Copper	μg	342	#1	Banana 345, spinach 570
Vitamin D (UV Enhanced)	μg	20	#1	Not present in plants
Vit B12	μg	0.1	#1	Not present in plants

respectively, were determined in four dried common cultivated species (Caglarirmak 2011).

For vegetarians, mushrooms are a unique source of vitamin B12 (Watanabe et al. 2014). This vitamin in mushrooms is especially found in the outer peel, suggesting that B12 is bacterium derived (Koyyalamudi et al. 2009).

The normal content of ascorbic acid is 150–300 mg/kg FM. The content in *Agaricus* spp. seems to be low. The content of ergosterol, the provitamin of ergocalciferol (vitamin D2), was reported to be 3000–7000 mg/kg DM (Kalac 2009; Mattila et al. 2002; Phillips et al. 2011). There are several reports (Ko et al. 2008; Koyyalamudi et al. 2009, 2011; Simon et al. 2011; Phillips and Rasor 2013) dealing with the effects of various ultraviolet irradiation of mushrooms on vitamin D2 formation from ergosterol as discussed ahead.

17.2.5 Minerals

The normal ash content of mushrooms ranges between 60 and 120 g/kg DM. Potassium is the main macro-element, while calcium and sodium are at the opposite side (Table 17.3, based on Kalac 2013).

Potassium foods are a must for any amateur athlete or weekend warrior. It plays a major role in maintaining fluid and electrolyte balance and is needed for nerve and muscle function. Mushrooms contain 360 mg of potassium per 100 g. A healthy, varied diet with plenty of potassium and low in sodium (salt) helps maintain healthy blood pressure. High blood pressure is a risk factor for heart disease.

Mushrooms are a source of phosphorus, and 100 g mushrooms will provide 11% of your daily phosphorus needs. The main role of phosphorus, in combination with calcium, is to form the basic structure of teeth and bones. Phosphorus is also needed for energy metabolism and is a critical part of a high-energy compound called ATP that is used during muscle contraction. In addition to minerals like calcium and zinc, mushrooms are a rich source of two important minerals, viz. selenium and copper.

Copper is a cardioprotective agent. Hundred grams of mushrooms provide over 20% of your daily needs for copper and 11% of your daily phosphorus needs. Similar to the B group vitamins, copper plays a vital role in energy production, brain function and the immune system. Copper is necessary for iron transport,

Table 17.3 Minerals in mushrooms (based on Kalac 2013)

Elements in ash	Content (g/kg DM)
Potassium	20–40
Phosphorus	5–10
Chlorine	1–6
Sulphur	1–6
Magnesium	0.8–1.8
Calcium	0.1–0.5
Sodium	0.1–0.4

maintaining normal skin and hair colouration, and is also an antioxidant, which protects cells from free radical damage.

Selenium is another essential mineral that is an antioxidant and helps to prevent free radical damage. A 100 g serve of mushrooms can provide nearly a quarter of your daily needs of selenium. Selenium works with iodine to produce thyroid hormones, plus it is vital for sperm production. It may help boost your immune system, slow age-related mental decline and even reduce your risk of heart disease, cancer, asthma symptoms, etc. (https://www.healthline.com/nutrition/selenium-benefits).

Many foods, of animal origin and grains, are good sources of selenium, but mushrooms are among the richest sources of selenium in the produce aisle. The amount of selenium in plant-based foods varies depending on the selenium content of the soil in which they were grown. In Punjab, some villages in two districts, Nawanshahr and Hoshiarpur, have very high selenium in soil and so too does the wheat and paddy straw produced on this soil. Use of these straws for growing mushrooms has shown that high amount of selenium gets accumulated in mushroom and by using such straws it is possible to produce selenium-rich mushrooms. However, there are dangers of excessive selenium intake as consuming high doses of selenium can be toxic and even fatal. Signs of selenium toxicity include hair loss, dizziness, nausea, vomiting, facial flushing, tremors and muscle soreness. While selenium toxicity is rare, it is important to stay close to the recommended amount of 55 μg/day.

17.2.6 Flavour, Taste Compounds, Pigments, Phenolics and Others

Many consumers highly appreciate the characteristic flavour of many mushroom species. The very typical character of mushroom aroma is ascribed to derivatives of octane (Kalac 2013). Mushrooms have natural glutamates that provide a unique taste to mushrooms. Pigments of various chemical groups occur in mushrooms and have been reviewed by Zhou and Liu (2010) and Velısek and Cejpek (2011).

Phenolic compounds are secondary metabolites possessing an aromatic ring with one or more hydroxyl groups, and their structures can be a simple phenolic molecule or a complex polymer. Palacios et al. (2011) evaluated total phenolic and flavonoid contents in eight types of edible mushrooms including *Agaricus bisporus* and concluded that mushrooms contain 1–6 mg of phenolics/g of dried mushroom and the flavonoid concentrations ranged between 0.9 and 3.0 mg/g of dried matter; the main flavonoids found were myricetin and catechin. *B. edulis* and *A. bisporus* presented the highest content of phenolic compounds. Phenolics, particularly phenolic acids, are the main mushroom antioxidants. Phenolic acids can be divided into two major groups: hydroxy derivatives of benzoic acid and *trans*-cinnamic acid (Kalac 2013).

Various other constituents in mushrooms include carboxylic acids, gamma-aminobutyric acid (GABA), ergothioneine (betaine of 2-mercapto-L-histidine), biologically active polyamine spermidine, agaritine and large number of other novel compounds (Kalac 2013).

17.3 Nutritional Benefits

17.3.1 The Only Vegetable with Vitamin D

Vitamin D is important for bones and muscle health. It is essential for calcium absorption, and it stimulates the synthesis of calcium transport proteins in the small intestine. It has been linked to immunity and protection against diabetes and various respiratory, cardiac and neurological diseases. Sources of vitamin D are sunlight, fish, animal products and wild mushrooms. Even though it can be produced in our body on exposure to sun, still these days majority of people are deficient in vitamin D due to changes in our lifestyle. Vitamin D deficiency is pandemic, yet it is the most under-diagnosed and under-treated nutritional deficiency in the world. Ritu and Gupta (2014) reviewed the work by various workers on vitamin D deficiency in India in Kashmir, Punjab, Haryana, Chandigarh, Delhi, Lucknow, Varanasi, Tirupati, Mysore, Kolkata, Mumbai, Pune and other cities spread over the country and highlighted the extreme degree in deficiency in all groups. For example, vitamin D deficiency in Delhi was around 90% or more in different groups (Table 17.4).

The two main dietary forms of vitamin D are D2, found in fungi, and D3, found in animals. Sun-drying and exposure to UV radiation increase vitamin D content in mushrooms. Such mushrooms are a potentially important source of dietary vitamin D (as vitamin D2) (Mau et al. 1998; Nölle et al. 2016; Simon et al. 2011). Vitamin D-enhanced mushrooms are the only non-animal food product with substantial amounts of bioavailable vitamin D. There are sporadic reports of Vitamin D in plants but there are many research gaps around vitamin D in plants (Lucinda et al. 2017).

Wild mushrooms are high in vitamin D as these naturally get exposed to sunlight. In contrast to this, dark-grown mushrooms have no vitamin D (Table 17.5). These have high concentrations of ergosterol in their cell walls. The presence of both ergosterol and vitamin D2 in mushrooms was first reported in the early 1930s

Table 17.4 A summary of study on Vit D deficiency in various categories in Delhi (based on various works published by Marwaha et al. (2005, 2011a, b, c))

Sample size	Group	% deficient
5137	Adolescents, urban school children	89.5
96	College girls	100
1346	Adults (>50 years)	91.2
521	Pregnant women	96.3
342	Lactating mothers	99.7
342	Breastfed infants	98.8

Deficiency I = 25(OH)D < 20 ng/mL; insufficiency = 20–29 ng/mL

Table 17.5 Vitamin D in UV-exposed and natural mushrooms

100 g Raw mushroom	Vitamin D2 in mushroom	
	Exposed to UV	Not exposed to UV (μg)
White button mushroom	26.2 μg	0.2
Portabella mushroom	28.4 μg	0.3
Brown or crimini mushrooms	31.9 μg	0.1
Morel (naturally exposed to sunlight)	–	5.1
Recommended daily allowance of vitamin D	15.0 μg	

Source: U.S. Department of Agriculture, ARS. FoodData Central (2019), fdc.nal.usda.gov

(Quackenbush et al. 1935). Exposing the mushrooms to UV-B or sunlight for 15 min or so converts ergosterol to vitamin D. By photochemical reaction, it changes to ergocalciferol. The calciferol then gets converted to 25(OH)D, calcidiol. The diol gets converted to 1,25$(OH)_2$ D, calcitriol that is involved in calcium absorption in the intestine (Cardwell et al. 2018). Alternative to UVB irradiation is pulsed UV exposure for 3–9 s, which is more effective and safe with no effect on quality (Koyyalamudi et al. 2011). High cost of a xenon pulsed UV instrument may be prohibitive for many growers.

Internationally recommended dietary allowance of vitamin D is about 10 μg/day, and recommendations vary across 15 μg/day in Europe, USA and Canada; 10 μg/day in the UK; and 5 μg/day in Australia and New Zealand (DRV 2017; DRI 2011; DRI-Can n.d.; SAC-UK 2016; NRV-Aust. 2006) [higher doses are recommended for elderly people in the USA and Canada (20 μg/day for 70+), and Australia and New Zealand (10 μg/day for 51–70 and 15 μg/day for 70+)].

Vitamin D-enhanced mushrooms using UV light are already on sale in many developed countries. We need to promote mushroom as the only vegetable with vit D and B12. Mushrooms are one of the only natural vegetarian sources of both vitamin B12, which is bacterium derived, and vitamin D, which, as described above, is produced by the conversion of ergosterol to ergocalciferol after exposure to ultraviolet (UV) light. Some varieties, such as crimini and portabella, contain higher levels of ergosterol, which on exposure to UV results in a higher amount of vitamin D (Table 17.5). Vitamin D-enhanced (or UV light-exposed) mushrooms are the only non-animal food product with substantial amounts of bioavailable vitamin D and, as such, have the potential to be a primary source of dietary vitamin D for vegans and vegetarians.

Mushrooms will generate vitamin D2 in response to exposure to UV radiation both during growing phase and post-harvest; however, commercial growers use UV lamps post-harvest for practical reasons (Cardwell et al. 2018). The most effective wavelength to stimulate the production of vitamin D2 in mushrooms is UV-B radiation (280–315 nm) (Jasinghe and Perera 2006).

Although the levels of vitamin D2 in UV-exposed mushrooms may decrease with storage and cooking, if they are consumed before the ‘best before’ date, vitamin D2 level is likely to remain above 10 μg/100 g fresh weight, which is higher than the level in most vitamin D-containing foods and similar to the daily requirement of vitamin D recommended internationally (Cardwell et al. 2018).

17.3.2 Mushrooms as Replacement of Meat and for Weight Control

Plant-based choices are beneficial not only for health but also for the environment. A study from the Culinary Institute of America and University of California-Davis, published in the Journal of Food Science, explored the flavour-enhancing properties of mushrooms and found that blending finely chopped mushrooms with ground meat (50:50 or even 80:20) enhances flavour and nutrition. This will reduce calorie, fat and sodium intake, while adding in B vitamins—riboflavin (28%), niacin (20%) and pantothenic acid (27%); enhance the overall flavour, because of double the impact of umami; and maintain flavour while reducing sodium intake by 25% (Myrdal Miller et al. 2014). A study showed that substituting mushrooms for lean ground beef in a main course of meal just once every week would save almost 20,000 cal or more than 5 pounds of body weight in 1 year (Cheskin et al. 2008).

17.3.3 Mushrooms and Umami

For many years, there have been four known taste sensations: sweet, sour, salty and bitter. Foods with natural glutamates provided a fifth taste, called umami. Umami is a Japanese term first coined by Kikunae Ikeda, professor of physical chemistry at the University of Tokyo, in 1908. It is derived from the Japanese word umai, meaning 'delicious'; umami is described as a savoury, brothy, rich or meaty taste sensation. It is the colloquial Japanese term for 'tasty', and Professor Ikeda used it to describe the taste of a broth made from seaweed, dried fish and shiitake mushrooms (Kurihara 2009). It is the natural glutamates that give mushrooms their deliciously rich, savoury 'umami' flavour that makes them a favourite among meat eaters and vegetarians alike (Mau 2005). To scientists, umami indicates a high level of glutamate, an amino acid and building block of protein. One of the best benefits of foods containing glutamate is that when they are added to meals, the salt content can be reduced by 30–40% without affecting the flavour (Mouritsen 2012). That means when you add mushrooms to a meal, you can cook with less salt. The natural glutamates (Zhang et al. 2013) in mushrooms are not to be confused with the monosodium glutamate (MSG) sometimes added to foods as a flavour enhancer. There is no MSG in mushrooms. Glutamates are also a signalling molecule in the nervous system of the gut, which can help signal fullness (Uneyama et al. 2008; Masic et al. 2014). Together, the fibre and glutamates in mushrooms may help control appetite (Delgado 2013).

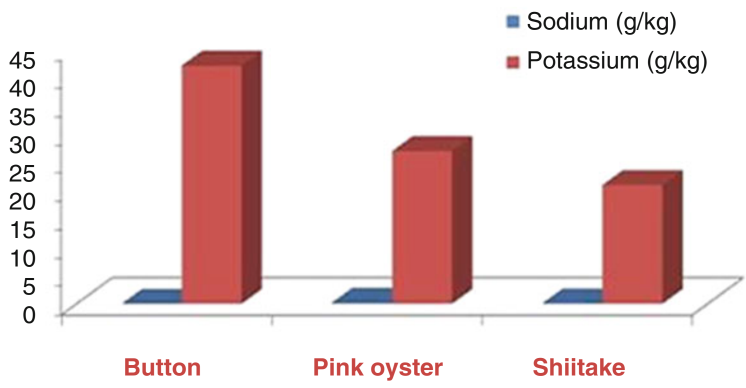

Fig. 17.7 Sodium and potassium in mushrooms

17.3.4 Mushrooms Help in Hypertension/Heart

As described earlier, mushrooms are good for heart as they have got low fat, no cholesterol and more of unsaturated fatty acids, and some of the mushrooms have compounds like lovastatin that is known to lower the cholesterol in the blood.

Moreover, mushrooms have low sodium and high potassium content, making it a suitable food for persons suffering from high blood pressure. Sodium is an essential nutrient—it helps to regulate blood pressure and maintain fluid balance in the body. However, too much sodium intake can increase blood pressure because it holds excess fluid in the body, putting extra strain on the heart. *The 2010 Dietary Guidelines for Americans* recommend limiting sodium intake to no more than 2300 mg a day and no more than 1500 mg a day with high blood pressure or risk factors for high blood pressure. Processed foods are major contributors for enhanced sodium intake. Mushrooms have negligible sodium (Fig. 17.7, based on ICAR-DMR data).

Mushrooms are rich in potassium (6%), which is another important mineral many people do not get enough of. It aids in the maintenance of normal fluid and mineral balance and can help control blood pressure.

17.3.5 Mushrooms Enhance Immunity

The immune system is made up of a network of cells, tissues and organs that work together to protect the body against infection and maintain overall health. Mushrooms, like other fruits and vegetables, can play a positive role in supporting a healthy immune system. There are a variety of compounds like beta-glucans and micronutrients as identified by the Linus Pauling Institute at Oregon State University that are important for supporting a healthy immune system including selenium and vitamins D and B6, which can be found in mushrooms (https://lpi.oregonstate.edu/mic/health-disease/immunity).

17.3.6 Mushrooms Regulate Digestive System

Dietary fibre assists in the digestion process (Guillamón et al. 2010). Mushroom fibre acts as a prebiotic because it resists digestion and becomes food for the healthy bacteria residing in the large intestine or bowel. Consumption of fresh mushrooms and a mushroom extract both showed beneficial effects on stool weight, microbiota, bowel strain, faecal odour and bad breath. Consuming white button mushrooms in replacement of red meat each day for 10 days was shown to have a positive effect on the gut microbiome and improved bowel function in individuals (Hess et al. 2018).

17.3.7 Mushrooms Are Gluten Free

Gluten is a type of protein found in many grains, such as wheat, rye and barley. Some people have sensitivity to gluten, such as people with celiac disease. Celiac disease, sometimes called celiac sprue or gluten-sensitive enteropathy, is an immune reaction to eating gluten. Mushrooms are naturally free of gluten and make a delicious and nutritious addition to a gluten-free diet (https://australianmushrooms.com.au/health).

17.3.8 Mushroom: Delight of Diabetics

Diabetes is a common condition where blood glucose levels rise above a normal healthy level. The dietary advice for people with diabetes is to eat mainly low sugar or low glycaemic index and minimally processed foods. Mushrooms have a low carbohydrate content, which means that mushrooms may have little effect on blood glucose levels, which could make them a good food choice for people with diabetes (Khatun et al. 2007; Sang-Chul et al. 2010). The glycaemic index (GI) is the measure of the effect a carbohydrate-containing food has on your blood glucose levels. The effect is an indication of the speed at which the carbohydrate in food is digested into glucose and absorbed into the bloodstream. GI of mushrooms is so low that it cannot be tested. Studies showed that the addition of mushrooms to a meal may help to lower the blood glucose levels in people with type 2 diabetes (Jayasuriya et al. 2015; Khatun et al. 2007; Sang-Chul et al. 2010).

17.3.9 Mushrooms as Antioxidants

Free radicals are unstable, highly reactive molecules that damage the skin, other tissues, DNA, etc. (ageing, cancer, etc). These are formed when oxygen interacts with certain molecules. Antioxidants are nature’s defence against the damaging effects of free radicals, guarding cellular structure and DNA, and thus have anti-ageing property. Mushrooms have a number of phenolic compounds/carotenoids, flavones, vitamins and minerals like selenium that act as antioxidants (Kozarski et al. 2015). In a study comparing 30 common vegetables, mushrooms were placed in the top five vegetables with the highest antioxidant capacity (Pellegrini et al. 2003). Mushrooms are also the highest dietary source of a unique sulphur-containing antioxidant called ergothioneine (Kalaras et al. 2017). They contain antioxidant vitamins and minerals such as riboflavin, copper and selenium, and polyphenols.

17.3.10 Mushrooms as Cosmeceuticals

In addition to food, supplements and drugs, mushrooms are used as cosmeceuticals. Various cosmeceuticals, including polysaccharides (e.g. soluble B-glucans, glucuronoxylomannan, sacchachitin, tyrosinase and other enzymes), are used by cosmetic companies because of their film-forming capability; ability to activate epidermal growth factor; anti-oxidative, anti-allergic, antibacterial and anti-inflammatory activities; and ability to stimulate collagen activity, inhibit autoimmune vitiligo and treat acne (Chang and Wasser 2012).

17.4 Mushrooms as Dietary Supplements

Dietary supplements are ingredients obtained from foods, plants and mushrooms that are taken, without further modification, separately from foods for their presumed health-enhancing benefits. Mushroom-derived preparations have a variety of names like dietary supplements, tonics, functional foods, nutraceuticals, phytochemicals, food supplements, nutritional supplements, mycochemicals, biochemopreventives and designer foods (Chang and Wasser 2012). There has been a rapid increase in the trade of medicinal mushrooms and these contribute about 31% of the world mushroom trade (Royse 2014). The regulations for supplements are under development and vary from country to country. For example, regarding the regulation of health foods in China, it was on 28th February 2009 that the National People's Congress passed the first comprehensive Food Safety Law (FSL), wherein health food is defined as food processed for health functions. The rules granted consumers a right of action to sue for compensatory and punitive damages.

Mushroom dietary supplements' regulatory framework in the USA involves facility registration. Ingredients must conform to statute, product forms should be limited to oral use. It is considered adulterated if a significant or unreasonable risk of illness or injury is present. Safety data must be submitted to the FDA for 'new dietary ingredients' 75 days before marketing, and the marketer must have substantiation for claims.

In India, we have certain regulations under the FSSAI that has set globally benchmarked safe food practices that include developing manuals for Food Safety Management Systems (FSMS) and setting up third-party audits and Indian certification for Hazard Analysis and Critical Control Points (HACCP) and General Hygiene Practices (GHP) for food businesses. We do have printed general documents, but there is need for specific guidelines for different groups of products including mushrooms. Many countries have commodity-specific guidelines. Problems in supplements in the global market are unverified health claims and lack of consistency in product over batches. There is need for quality standards.

17.5 Mushrooms as Medicine

Many mushrooms that are used as food also have medicinal value. For example, oyster mushroom is a source of the drug class of statins (lovastatin) used for lowering cholesterol and so preventing cardiovascular disease. Similarly, shiitake has lentinan that is considered to have anti-tumour, anti-thrombosis, anti-asthma, antivirus and anti-cholesterol activities. Some of the mushrooms are still collected for medicinal use. The important example is *Cordyceps sinensis* that has cordycepin (3′-deoxyadenosine, a derivative of the nucleoside adenosine) considered to provide energy and endurance. Mushroom polysaccharides like β-D-glucans linked to proteins have been tested on humans, as these are considered to enhance immunity. Immunoceuticals isolated from 30 mushroom species have demonstrated anti-tumour activity in animal treatments (Chang and Wasser 2012). Some of the important medicinal mushroom species are *Lentinus edodes*, *Grifola frondosa*, *Schizophyllum commune*, *Ganoderma lucidum*, *Trametes versicolor*, *Inonotus obliquus*, *Flammulina velutipes*, *Phellinus linteus* and *Cordyceps sinensis* (Table 17.6).

There are many mushroom products that reduce the side effect of radiotherapy and chemotherapy. Medicinal mushrooms and fungi have more than 130 medicinal functions, like anti-tumour, immunomodulating, antioxidant, radical scavenging, cardiovascular, cholesterol-lowering, antiviral, antibacterial, antiparasitic, antifungal, detoxification, hepatoprotective, antidiabetic, antiobesity, neuroprotective and

Table 17.6 Some important medicinal mushrooms and their active ingredients

Species	Compound
Lentinus edodes	Lentinan (*T-cell-oriented immunopotentiators)*
Grifola frondosa	Grifon-D (breast, prostate, lung liver cancer)
S. commune	Schizophyllan (*T-cell-oriented immunopotentiators*)
Ganoderma lucidum	GLPS polysaccharide fraction
Trametes versicolor	PSK (Krestin)—a leading cancer drug
Trametes versicolor	PSP (polysaccharide peptide)—immunostimulators
Inonotus obliquus	Befungin—an anti-cancer drug
Flammulina velutipes	Proflamin—an anti-tumour agent
Phellinus linteus	Ethyl acetate fraction
Cordyceps sinensis	Cordycepin—anti-tumour and anti-metastatic

Based on Chang and Wasser (2012), International Journal of Medicinal Mushrooms, 14(2): 95–134 neuroregenerative effects. Many, if not all, higher Basidiomycetes mushrooms contain biologically active compounds in fruit bodies, cultured mycelia and cultured broth. Special attention has been paid to mushroom polysaccharides. Numerous bioactive polysaccharides (especially Β-glucans) or polysaccharide-protein complexes from medicinal mushrooms seem to enhance innate and cell-mediated immune responses, and they exhibit anti-tumour activities in animals and humans. Many, if not all, higher Basidiomycetes mushrooms contain different types of biologically active high- and low-molecular-weight compounds (triterpenes, lectins, steroids, phenols, polyphenols, lactones, statins, alkaloids and antibiotics) in fruit bodies, spores, cultured mycelia and cultured broth (Wasser 2017).

Substances derived from medicinal mushrooms are used in immunodeficient and immunodepressed patients to prevent immune disorders; patients receiving chemotherapy or radiotherapy for maintaining a good quality of life; patients with different types of cancers, chronic blood-borne viral infections (hepatitis B, C and D), different types of anaemia, human immunodeficiency virus/AIDS and other viruses; patients with chronic gastritis and gastric ulcers caused by *Helicobacter pylori*; and people suffering from dementia (especially Alzheimer's disease) (Wasser 2017).

Despite significant use of medicinal mushrooms, their positive effects have been insufficiently studied in clinical trials. NIH—US National Library of Medicine (ClinicalTrials.gov.)—lists around 3.7 lakh human trials (ongoing or completed) in 219 countries. Of these, till 2020, there were 82 trials on mushrooms. Of these, 16 were on Ganoderma, 13 on shiitake, 8 on Agaricus, 4 on Pleurotus and 8 on mushroom + vit D. As can be seen in the last row of Table 17.7, trials are being initiated on the use of mushrooms against COVID-19.

Michelle Blumfielda and co-workers (Blumfielda et al. 2020) examined the reports on health effects and bioactive components in *Agaricus bisporus* on humans. It involved screening more than 5000 studies (full report on https://doi.org/10.1016/j.jnutbio.2020.108453). They concluded that *A. bisporus* mushrooms are sources of beta-glucans, ergosterol, ergothioneine, vitamin D and an antioxidant compound usually reported as flavonoids, with varying concentrations depending on the type of mushroom, cooking method and duration, and UV-B exposure. UV-B-exposed mushrooms increase and maintain serum 25(OH)D levels to a similar degree as vitamin D supplements. Further, the evidence shows that *A. bisporus* may lower the risk of cancer and could potentially improve metabolic syndrome, immune function and gastrointestinal health.

Modern medical practice relies on highly purified pharmaceutical compounds whose activity and toxicity show clear structure-function relationships. Mushroom products like many herbal medicines contain mixtures of natural compounds with no detailed chemical analyses and mechanism. To translate these into acceptable evidence-based therapies, there is a need for human trials. A number of trials have been completed and underway.

All mushrooms found in nature are not edible. Some are edible, few are inedible and a few mushrooms are poisonous. Many poisonous mushrooms apparently look like edible species, and as a result, every year there are hospitalizations and deaths due to consumption of mushrooms collected from the nature. There are different

Table 17.7 Human trials on mushroom (ClinicalTrials.gov)

Title	Conditions	Locations
Evaluating Vitamin D Content in Mushrooms	Vitamin D deficiency	Boston Medical Center, Boston, Massachusetts, United States
Bioavailability and Biological Effects of Vitamin D2 Contained in Mushroom	Vitamin D deficiency/ prediabetes	Icahn School of Medicine at Mount Sinai, New York, New York, United States
Dietary Compensation With Substitution of Meat Products With White Button Mushrooms	Obesity	Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, United States
Evaluation of the Effect of a Shiitake Extract on Lipid Profile in Subjects With Moderate Hyperlipidemia	Hyper-cholesterolaemia Hyperlipidaemia	Institute for Health Research IdiPAZ, Madrid, Spain
Efficacy and Safety of Cauliflower Mushroom Extract on Promotion of Immunity	Immunity	Clinical Trial Center for Functional Foods; Chonbuk National University Hospital, Republic of Korea
White Button Mushroom Extract in Preventing the Recurrence of Breast Cancer in Postmenopausal Breast Cancer Survivors	Breast cancer Cancer survivor	City of Hope Comprehensive Cancer Center, Duarte, California, United States
Clinical Trial of Trametes versicolor in Women With Breast Cancer	Breast cancer	Masonic Cancer Center, University of Minnesota, United States
Does Maitake Mushroom Extract Enhance Hematopoiesis in Myelodysplastic Patients?	Myelodysplastic syndrome	Memorial Sloan Kettering Cancer Center, New York, New York, United States
Agaricus blazei Murrill (ABM) in Patients With Inflammatory Bowel Disease (IBD)	Inflammatory bowel disease	Oslo University Hospital, Department of Surgery, Oslo, Norway
The Supplementary Effects of the Extract of Agaricus blazei Murrill on Type II Diabetes Mellitus (DM)	Diabetes mellitus, type 2	Chung-Hua Hsu, Taipei, Taiwan
Efficacy of Psilocybin in Obsessive-Compulsive Disorder (OCD): a Double-Blind, Placebo-Controlled Study. (recruiting)	Obsessive-compulsive disorder	Connecticut Mental Health Center, New Haven, Connecticut, United States
Mushroom-based Product for COVID-19 (Recruiting)	COVID-19	University of California, Los Angeles/San Diego, United States

Table 17.8 Some poisonous mushrooms

Species	Mode of poisoning
Clitocybe nuda	When eaten raw
Verpa bohemica	When eaten in large quantity
Gyromitra esculenta	Unless parboiled and fully cooked
Coprinus atramentarius	Only under certain conditions—with alcoholic beverages
Amanita phalloides	Regardless of the manner of preparation
Psilocybe semilanceata	Hallucinogenic

mechanisms of poisoning, and as a result some cause discomfort, a few are hallucinogenic and some are lethal like *Amanita phalloides* (Table 17.8).

17.6 Mushrooms for Entrepreneurship

Mushroom as a vocation does not mean just cultivation. It has various components like spawn production, compost production, cultivation, canning, processing and marketing. Each of these is a profitable venture. All of these components require little land and can be done in isolation or combined into a single mushroom production and trade activity. Comparison of the various agricultural activities (Singh et al. 2019) shows that growing mushroom is a highly profitable venture (Table 17.9). It, however, requires better training, skill and dedication in addition to finances.

In India, four mushroom species, viz. *Agaricus bisporus* (button), *Pleurotus ostreatus* (oyster), *Volvariella volvacea* (paddy straw mushroom) and *Calocybe indica* (milky mushroom), are mainly cultivated (Fig. 17.8), and the share of button mushroom is around 70%. Even though each mushroom has specific cultivation technology protocol, basic steps in cultivation are same. These are preparation of seed (spawn); preparation of medium for growing mushroom (called substrate or compost); cropping under specific environmental conditions of temperature, humidity, carbon dioxide, light, etc.; and processing and marketing. Just like other crops, the amount of spawn (seed) required and method of making compost and cropping are different for each mushroom. However, there are some basic requirements that should be met while setting up any mushroom production unit. These are selection of a proper site, having a proper link to road, and round-the-year availability of labour, raw materials including spawn, electricity and water in adequate quantity and reasonable cost; good training/education (ICAR-DMR conducts training for entrepreneurs); proper project report.

Button mushroom cultivation in our country is done both under controlled conditions and as a seasonal activity. Other mushrooms like oyster, milky mushroom and paddy straw mushroom are cultivated as seasonal activity in huts. Oyster

Table 17.9 Mushroom cultivation—a profitable venture

	Investment (lakh/ha)	Production (ton/ha)	Water requirement	Annual profit (Rs./ha)
Traditional agriculture (wheat and rice)	1.5	4.5 tons of wheat and 6 tons of rice	2000 L/kg	0.4 lakh
High-tech polyhouse	140	Exotic vegetable, flowers	1000 L/kg	15 lakhs
Seasonal cultivation of mushroom (4–5 months)	50	80	40 L/kg	10 lakhs
Commercial cultivation of button mushroom	600	500	25 L/kg	100 lakhs

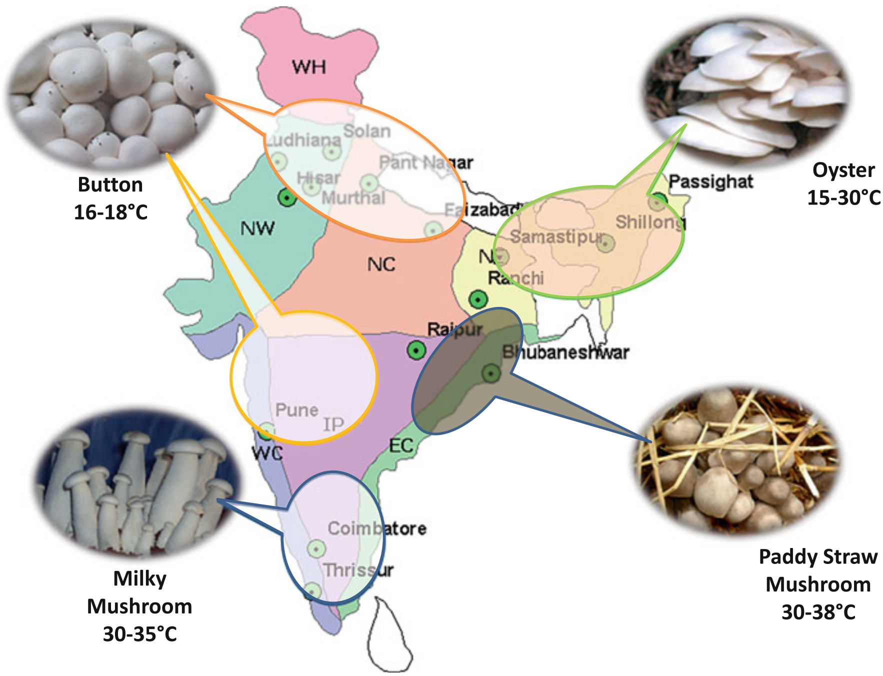

Fig. 17.8 Production regions of different mushrooms in India

mushroom is more popular in Eastern parts, though it is grown throughout the country as a small-scale activity; milky mushroom is mainly cultivated in the South, and paddy straw mushroom is grown under shade of trees in coastal areas of Odisha (Fig. 17.8). Spawn for all these mushrooms is prepared by the public as well as private sector. In initial stages, spawn production was done by the public sector, but now the contribution of the private sector is much higher. Despite the production at various levels, the availability of spawn is a limiting factor in the growth of mushroom in our country. Hence, setting up a spawn production lab is an important entrepreneurial activity. Spawn production in India, however, is still by using lab method, whereas at international level, there is monopoly in production and firms like Sylvan use V-blender with total automation of spawn production. For our conditions, the current approach seems to be more viable as supply chains required for long-distance transport of spawn under controlled conditions are not in place. However, there is need for greater emphasis on improved varieties and methods of culture maintenance so that strains may not loose viability. For commercial production of a number of mushrooms other than button mushroom (wood fungi like *Hypsizygus marmoreus*, *Flammulina*, shiitake and king oyster), we do need liquid spawn production technology and automation. It is commonly used in China, Japan, Korea, etc. for cultivation of mushrooms other than button mushroom. There, most of the commercial units have complete automation for bottle/bag/log cultivation.

In addition to these mushrooms, there are others that are being cultivated in some parts. These include shiitake, *Cordyceps militaris*, king oyster, portabella, *Ganoderma*, etc. But their contribution at present is miniscule (Singh 2011). ICAR-DMR has cultivated over 20 types of mushrooms including experimental cultivation of *Morchella*.

Cultivation in our country is still at nascent stages. Initially in 60s, we started with the cultivation of button mushroom in hill states as a seasonal activity. Soon, a number of export units of button mushroom were established, most of which failed to survive due to total dependence on technology from outside. Lack of peat moss as casing soil and non-adoption of cookout by most of the units were the reasons for their failure. Now proper cropping rooms with automation for control of temperature, humidity and carbon dioxide are being established for button. For oyster, paddy straw and milky mushrooms, the cultivation is still being done in huts as a seasonal activity. *Cordyceps militaris*, a medicinal mushroom, is being cultivated in India in states like Haryana, Uttarakhand, Punjab and UP, under controlled conditions.

Mushroom Days are held every year in the Netherlands, China and various other countries to showcase the machinery, products and other latest technologies. In Australia, mushroom growers pay a statutory levy on all *Agaricus bisporus* spawn (seed), 75% of which is spent on marketing and promotion. There is need for cooperative efforts for promoting mushrooms. In mushroom cultivation, the limiting factors are non-availability of quality spawn, lack of assured electricity, lack of trained manpower and limited literature in local language on both cultivation and consumption. In addition, there are many myths and misinformation about mushrooms and lack of proper scientific training.

Problems are in the availability of raw materials, standard farm designs that are essential for mechanization and development of standard protocols. Considering rising labour costs, mechanization will be essential in coming days. Environment will be an issue someday. Let us do before it causes damage. When there will be growth, disposal of SMS will be a problem. Casing can be separated from compost as the former is reused. Part of the spent compost can be recycled while making compost or can be used for making casing soil.

Sum Up Growth is a function of positive interaction among researchers, extension workers, farmers and industry and policymakers. There is a need for a synchronized approach in a systematic manner for generating the awareness about mushroom consumption and proper technologies for mushroom cultivation, development of marketing chains for supply of fresh mushrooms and production of indigenous mushroom products. 'Mushroom growing isn't just a rapidly expanding agribusiness; it's also a significant tool for the restoration, replenishment and remediation of earth's overburdened ecosphere' (Paul Stamets).

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Aquatic Vegetables for Nutrition and Entrepreneurship

18

Jitendra Singh, Hina Chauhan, Versha Kumari, and Rekha Singh

Abstract

Aquatic vegetables are predominantly in vogue where they are naturally available in plenty. In India, a number of aquatic vegetables, viz. water chestnut (*Trapa* spp.), water spinach (*Ipomoea aquatica* Forsk.), lotus root (*Nelumbo nucifera*) and makhana (*Euryale ferox* Salisb.), are grown sporadically/commercially. Aquatic vegetables are eco-friendly, least suffer from any major diseases and pests and can be raised without applying any chemicals. They are rich in nutrition, dietary fibres, phyto-chemicals and antioxidants and play a pivotal role in reducing malnutrition in general and micronutrient malnutrition in particular. Apart from the nutritional and medicinal importance adhered to the aquatic vegetables, they also contribute significantly to maintaining the wetland ecosystem. Demand of by-products of aquatic vegetables like makhana pop, water chestnut flour and lotus root in urban market is pronouncing day by day due to its dietary and therapeutic properties. Some aquatic vegetables like water spinach also ensure availability of fresh vegetables round the year to the consumers. In urban areas, it can also be cultivated under terrace gardening in a container and wall culture as a vertical farming for producing healthy and hygienic veggies. Neglected water bodies/swampy land can be used for remunerative cultivation of aquatic vegetables. These vegetables help in purifying water by reducing current velocity and allowing deposition of sediment for removal of inorganic pollutants (nitrate, phosphate, etc.) from water bodies. Nowadays, the integrated approach for cultivating various horticultural crops on surrounding bunds of water bodies with aquatic vegetables and fish culture is emerging as a promising and sustainable agricultural method for higher production and returns per unit area. In addition to the importance of aquatic vegetables in the preparation of healthful

J. Singh (✉) · H. Chauhan · V. Kumari · R. Singh
Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India

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food, it has a great religious value as well. It serves as an essential additive with remarkable benefits in industrial sectors like textile, paper pulp, fertilizer, fish food, compost and biogas fuel. It also provides aesthetic opportunities with fewer requirements of inputs as well as new venture to begin entrepreneurship in urban and peri-urban areas.

Keywords

Aquatic vegetables · Nutrition · Entrepreneurship · Sustainable agriculture · Wetland ecosystem

18.1 Introduction

Apart from rich diversity of terrestrial vegetables, the country is a natural abode of a number of aquatic vegetables thriving in water bodies, viz. lakes, lagoons, ponds, ditches and marshy wet places. Valuable information on the number of aquatic edible greens is found across the globe in various submerged places lying in tropical, subtropical and temperate regions. In India, a number of aquatic vegetables, viz. water chestnut (*Trapa* spp.), water spinach (*Ipomoea aquatica* Forsk.), lotus root (*Nelumbo nucifera*) and makhana (*Euryale ferox* Salisb.), are grown sporadically/ commercially. Aquatic vegetables are eco-friendly, least suffer from any major diseases and pests and can be raised without applying any chemicals. They are rich in nutrition, dietary fibres, phyto-chemicals and antioxidants and may play a pivotal role in reducing the malnutrition in general and micronutrient malnutrition in particular. Apart from nutritional and medicinal importance adhered with the aquatic vegetables, they play an important role in maintaining the wetland ecosystem. In India, the number of aquatic plant species exceeds more than thousand; however, very limited efforts have been made to collect, characterize and maintain the genetic wealth of aquatic vegetables. In recent past, study made on the role of aquatic plants in bioremediation has proved to be a boon in mitigating the several environmental problems. The aquatic vegetation in India accounts for 9% in post-monsoon (1.32 Mha) and 14% in pre-monsoon (2.06 Mha) (source: National Wetland Atlas of ISRO 2011).

Water Spinach

Water Chestnut

Lotus Root

Swamp Taro

Makhana

18.2 Water Spinach

Water spinach (*Ipomoea aquatica* Forsk.) is an important leafy aquatic or semi-aquatic tropical or subtropical vegetable, which belongs to the family Convolvulaceae. Its species originated in China and is commonly known as aquatica morning glory, Chinese water spinach, kangkong, swamp cabbage, swamp morning glory, water convolvulus, karmi ka saag/kalmi bhaji (Hindi) and karmata bhaji (Chhattisgarh). Water spinach is herbaceous and annual or perennial in nature, with long, hollow stem possessing a large number of air passages and rooting at the nodes. The young terminal shoots and leaves of *I. aquatica* are eaten as leafy vegetable and as green salads (Ismail et al. 2004). It is distributed throughout East, South and Southeast Asia and also grown throughout India. Water spinach is a very suitable crop for cultivation under urban and peri-urban conditions, and it can also be cultivated at terrace as container gardening.

18.2.1 Genetic Resources

There are two major cultivars of water spinach: Ching Quat, also known as 'green stem' water spinach, has narrow leaves and white flowers and is usually grown in moist soils. Pak Quat, also known as 'white stem' water spinach, has arrow-shaped leaves and pink flowers. India is rich in biodiversity of leafy vegetables including water spinach; 26 genotypes have been collected from various agro-climatic zones of Chhattisgarh region by Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh. IGWS-2 has been found to be the best performing genotype among all others under container gardening (Chauhan 2019) and vertical farming (Chandrakar 2019). Also, this genotype has the higher amount of major micronutrient availability as reported by Kurrey (2018).

18.2.2 Importance and Uses

White flower coloured genotypes have vigorous foliage with thick stem/vine and are high yielding with less water requirement and suitable for semi-aquatic condition and vertical and terrace gardening. They are used for green salad as well as for culinary purpose. On the other hand, purple flower coloured genotypes are medium to low yielding and require marshy land, less foliage with thin/vine stem and comparatively more water. They are used for culinary purpose. Land scarcity is one of the important factors in urban area, which can be overcome through terrace gardening and vertical farming. This ensures availability of fresh vegetables and provides aesthetic opportunities with less requirement of inputs. The fast-growing nature of water spinach makes it the best alternate for terrace gardening and vertical farming.

Foliage of water spinach (per 100 g) contains	Quantity	Foliage of water spinach (per 100 g) contains	Quantity
Carbohydrates	3.14 g	Folate (B9)	57 μg
Dietary fibre	2.1 g	Vitamin C	55 mg
Protein	2.6 g	Calcium	77 mg
Vitamin A	3.15 μg	Iron	1.67 mg
Thiamine (B1)	0.03 mg	Magnesium	71 mg
Riboflavin (B2)	0.1 mg	Phosphorus	39 mg
Niacin (B3)	0.9 mg	Potassium	312 mg
Pantothenic acid (B5)	0.141 mg	Sodium	113 mg
Vitamin B6	0.096 mg		

Nutrient Database of Water Spinach (USDA 2018)

18.2.3 Economics of Water Spinach

The water spinach requires very less input for its cultivation, about Rs. 75,000 for cultivation per hectare throughout the year. If water spinach is sold at a rate of Rs. 5/kg, then gross return will be Rs. 175,000 with net profit of Rs. 100,000/ha in a year. If grow water spinach under wall culture in pot size 0.68 m × 0.48 m, total cost of cultivation will be around Rs. 121/pot and its gross return will be Rs. 277 with net profit of Rs. 156.

Water spinach normally requires frequent water supply as it is aquatic/semi-aquatic in nature, which can be a difficult task if planted in open fields where water availability is not sufficient. Growing of water spinach in containers under such conditions can be a very useful option as it will be easy to fulfil the water requirement of the container crop as compared to the water requirement of the field crop (Chauhan 2019). Also, water spinach when cultivated in terrace gardening and vertical farming produces healthy and hygienic vegetable. This provides a new venture to begin entrepreneurship in urban areas and a revolutionary approach to produce year-round highly nutritious and fresh vegetables in urban areas. It is easy to grow with less input and is an excellent option for combating the problem of contamination from swampy area cultivation. Various dishes of water spinach include water spinach soup with black salt and black pepper powder added (famous in Northeast India) and water spinach stir-fried spicy curry with carrot mix (famous in Northeast India). Water spinach pakoda is popular, and also water spinach is used as a main ingredient in salads.

18.2.4 Production

Water spinach is grown in marshy land and cultivated in puddled field as well as in semi-aquatic condition. It can be grown year-round in the tropics, and optimal temperature required for growth is 20–30 °C. It is propagated through seeds and vine cuttings (30 cm) with spacing of 20 × 10 cm (P-P × R-R). There is no need of fertilizer under field condition. For container gardening, apply water-soluble fertilizer (WSF) of NPK in every alternate week. Under container gardening, Pandey (2016) observed the effect of different organic media on foliage yield of water spinach and found black soil (50%) + paddy husk (50%) is best among all. The crop matures for first harvest after 1–1.5 month of planting and can be harvested every week afterwards. Average yield is around 350 q/ha in open-field condition, 120 kg/container (size 3 × 2 × 1 ft) under container gardening and 1.47 (kg/m^2)/harvest in wall culture.

18.3 Water Chestnut

Water chestnut (*Trapa natans* var. *bispinosa* Roxb.) is an important aquatic vegetable, which belongs to the family Lythraceae. Its species originated in warm temperate parts of Eurasia and Africa and is commonly known as Singhara, Pani Phal, Pani Singhara, Jalphala or Smgtakah (Sanskrit), Karimphola (Malayalam), Shingade (Marathi), Cimkhara (Tamil) and Trapanatans in different parts of India.

18.3.1 Genetic Resources

Collection and characterization of improved genotypes of water chestnut in low-lying areas of Chhattisgarh have been done. Genotypes of chestnut such as CW-01 (Seoni, MP), which is a red-coloured chestnut, spikeless, sweet in taste, big size, round shape and easy to harvest due to absence of spike and has soft skin and shorter plant height with less water depth requirement; CW-02 (Balaghat, MP), which is a dark-green-coloured chestnut, spikeless, less sweet in taste, small size and round in shape, easy in harvesting due to absence of spike and low water depth requirement; CW-03 (Dhamtari and Raipur), which is green coloured, with strong spike, medium in size, good starch content, difficult in harvesting, good keeping quality, more plant height and required more water depth; and CW-04 (Rajnandgaon), which is red coloured and medium sized, with small spike present but sharp, poor keeping quality and medium height.

Importance and Uses

Variabilt in Water Chestnut

18.3.2 Importance and Uses

Water chestnut are rich sources of carbohydrate, starch, dietary fibre, riboflavin, vitamin B6, potassium and magnesium. It is consumed as vegetable and flour ‘singhare ka atta’ to prepare flattened bread (Phalahar diet) and sweet dishes. It reduces current velocity and allows deposition of sediment and inorganic pollutant (nitrate, phosphate, etc.) removal and hence purifies water. It is also used as an additive in paper pulp, fertilizer, fish food, compost and biogas fuel (i.e. methane generated from organic material via anaerobic digestion). Chestnut relieves cough, treats urinary infection and has antibacterial, antiviral, anti-cancerous, antioxidant, analgesic, anti-inflammatory and anti-diabetic properties (Shalini and Raghav 2019) . They are also said to have been used in offerings to the ‘darker god’, and the nuts are advertised on the internet as charms to ward off evil.

Neutritional Value of Water chestnut

Nutrients	Percentage	Minerals	Quantity
Moisture	70.35	Phosphorus (mg/100 g)	121
Energy (kcal)	115.52	Potassium (%)	5.22
Protein	4.40	Sodium (%)	0.64
Fat	0.65		
Carbohydrates	22.30	Copper (ppm)	430
Fibre	2.05	Zinc (ppm)	600
Ash content	2.30		
		Vitamin ‘C’ (mg)	1.1
		Calcium (mg/100 g)	32

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18.3.3 Production

Edible part of chestnut is fruit/nut, and it is propagated through mature nuts and suckers. In India, it is commonly cultivated in J&K, UP, MP, CG, West Bengal, Jharkhand, Bihar, Gujarat and Maharashtra. It is extensively grown in Darbhanga, Madhubani and Samastipur districts of Bihar. It thrives in tropical and subtropical region as a submersed plant community with optimum pH neutral to slightly alkaline. The plant is well adapted to life at the water’s edge and prospers even when stranded along muddy shores. It requires 20–35 °C for seed germination, flowering and fruiting and rich, friable and well-manured or fertilized soil. It is propagated by seed, and transplanting is done at first fortnight of June (2–3 plants at a distance of 1.5 × 1.5 m spacing (P-P × R-R)).

Organic manure required by the crop is 15 t/ha, NPK 100:60:40 kg/ha. Minimum 1 ft water should be maintained. Harvesting of fruit is usually done at the month of September till end of the November with yield 2500–3500 kg/ha.

18.3.4 Economics of Water Chestnut Cultivation at Farm Pond

The average yield of water chestnut will be 20 t/ha if planted in pond system @ 10,000 plants per hectare with a total input cost of Rs. 70,275. If the nuts are sold at a rate of Rs. 10/kg, total income will be Rs. 200,000. In such case, the net economic return will be Rs. 129,725/ha in a year.

18.4 Lotus Root

Lotus root (*Nelumbo nucifera*) is an important aquatic vegetable which belongs to the family Nelumbonaceae. Its species originated in Southeast Asia and possibly Africa and is commonly known as Lotus kakri (North India), Dhais (Chhattisgarh) and Kamal Gatta.

18.4.1 Genetic Resources

There are two varieties of lotus, namely *Nelumbo nucifera* var. *alba* (white type) and *Nelumbo nucifera* var. *rubra* (red type). Very abundant germplasms exist all over the world, which display variable genetic backgrounds and phenotypes, especially in Asia. Around 49 genotypes have been collected by Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.).

18.4.2 Importance and Uses

Lotus root is one of the moderate-calorie root vegetables. 100 g root stem provides about 74 cal. Nevertheless, it is composed of many health-benefiting phyto-nutrients, minerals and vitamins. It rhizome is an excellent source of dietary fibre and helps to reduce blood cholesterol, sugar, body weight and constipation conditions. Fresh lotus root is one of the excellent sources of vitamin C. It helps the body to protect from scurvy as well as develop resistance against viral infections, boosts immunity, improves wound healing and helps to scavenge cancer-causing harmful free radicals from the body. It stimulates collagen production in the body that is responsible for the skin's firmness. In addition, the root provides healthy amounts of some essential minerals like iron, zinc and magnesium, which act as a cofactor for many vital enzymes. It composes agreeable ratio of sodium to potassium. Sodium gives a sweet taste to the root, and potassium counters the adverse effects of sodium by regulating heart rate and blood pressure by relaxing the blood vessels and further preventing contraction and rigidity. The excessive potassium content in lotus roots absorbs the excess sodium and increases the production of urine. Thus, the roots help in preventing excess water retention. Lotus root is known for strengthening the respiratory system of a human body, which ultimately helps a person to fight with a number of diseases. Further, the root contains moderate levels of some of the valuable B complex group of vitamins such as pyridoxine (vitamin B6). Adequate pyridoxine levels help to control nervous irritability, headache and tension. It also cuts heart attack risk by controlling harmful homocysteine concentrations in the blood. The rhizome extract has anti-diabetic (Mukherjee et al. 1996a) and anti-inflammatory properties due to the presence of asteroidal triterpenoid (Mukherjee et al. 1996b). Rhizomes are used for pharyngopathy, pectoralgia, spermatorrhoea, leucoderma, smallpox, diarrhoea, dysentery and cough.

Lotus root (per 100 g) contains	Quantity	Lotus root (per 100 g) contains	Quantity
Energy	74 kcal	Pyridoxine	0.258 mg
Carbohydrates	17.23 g	Riboflavin	0.220 mg
Protein	2.60 g	Vitamin C	44 mg
Total fat	0.10 g	Sodium	40 mg
Cholesterol	0 mg	Potassium	556 mg
Dietary fibre	4.9 g	Iron	1.16 mg
Folates	13 μg	Magnesium	23 mg
Niacin	0.400 mg	Zinc	0.39 mg

Nutrient Database of Lotus Root (USDA 2018)

The seeds are used as Kamal Gatta (medicinal use), flowers for worship, leaf for serving of the food and root as Kamal kakdi/Dhais. The seeds from a lotus seed head can be eaten when they are green, and they will have a sweet flavour and can be eaten like peas. If wait until the seeds begin to turn brown, the seeds will have a nuttier taste. The seeds can be ground into paste and used to make pastries. Seeds can also be ground into flour for use in baking. After drying, it is used in the formation of religious garland.

Lotus seed (per 100 g) contains	Quantity
Protein	10.6–15.9%
Crude fat	1.93–2.8%
Carbohydrate	70–72.17%
Crude fibre	2.7%
Ash	3.9–4.5%
Energy	348.45 cal/100 g
Chromium	0.0042%
Sodium	1%
Potassium	28.5%
Calcium	22.1%
Magnesium	9.2%
Zinc	0.084%
Iron	0.199%

Nutrient Database of Lotus Seed (USDA 2018)

Kamal kakdi is the stem of the lotus plant and can be used to make a variety of dishes such as Lotus root curry, a popular healthy dish of North India.

Lotus root pickle

18.4.3 Production

Although mainly grown in tropical and subtropical regions, lotus root can withstand a considerable degree of frost and in India may be found from sea level up to 1800 m (Sou and Fujishige 1995). The lotus grows in water up to 2.5 m deep. The minimum water depth is about 30 cm. In colder climates, such a low water level, which heats up more quickly, is helpful for better growth and flowering. Lotus germinates at temperatures above 13 °C.

18.4.4 Planting Procedure

Lotus root can be propagated from small pieces of rhizome having at least one eye, or from seed. Approximately 45 kg of rhizome pieces are used to plant 1 ha, or 10–12 kg of seed. Planting density is low because of the very rapid growth of the rhizomes, reported as up to 15 m^2 per year. A number of methods are described for its cultivation; among them, the following methods are economic:

1. Pieces of rhizome are planted with the eyes just above the soil surface, and the water level is maintained at about 1 m throughout their growing period.
2. Pieces of rhizome are placed horizontally about 15 cm below the soil surface, and water is allowed to cover the soil, but with the crown of the developing plant just breaking the surface of the water. The water level is raised as the plant develops.
3. A method of planting in a filled pool or pond is to put sprouting pieces in a basket, pot, tub or other suitable container filled with a mixture of soil and compost or FYM, and then place the container in the pool in such a way that the crown of the plant is just above the water surface. The container should be on bricks or stones, and as new growth appears, the container is lowered by removal of bricks to maintain the crowns just on or above the water surface.
4. When it grown by seed as a propagating material, the seedlings are raised in nursery beds and planted out in the ponds after about 2 months.

The stolon is ready to harvest 2–3 months after planting. It must be harvested before flowering. Harvesting the stolon is done manually. The stolon is pulled out of the water by pulling and shaking the young leaves in the shallow water. Three months after planting, the first leaves and flowers can be harvested. The harvest of flowers is usually done by hand during 3–4 months. Seeds and seed pods can be harvested when they turn black at 4–8 months after planting. After sun drying for 2–3 days, they are processed by mechanical tools to separate seed coats and embryos (Tian et al. 2009).

The rhizomes are ready for consumption in approximately 6–9 months. Early varieties are harvested in July until September and late varieties from October until March. The large, starch-rich rhizomes are easy to dig out from the drained soil. In small-scale production, they are harvested by hand using fork-like tools. In India, the crop is reported to yield (root) 3.5–4.5 t/ha.

Cultivation of Lotus in Field Condition

Tender lotus nut

Tender lotus nut

18.4.5 Pond vs. Field Cultivation

Particulars	Pond condition	Field condition
Cultural practices	Difficult	Easy
Insecticide-pesticide application	Difficult	Easy
Weeding	Difficult	Easy
Crop taken in a year	Digging is possible only after water level down up to waist region	3 times in a year
Digging	Difficult, only by the skilled labour	Easy to harvest
Intercropping	Lotus-water chestnut-fish	Lotus-water chestnut
Economics (net monetary profit/ha)	Rs. 15,000–20,000	Rs. 80,000–90,000

18.5 Swamp Taro

Swamp taro (*Colocasia esculenta* var. *stoloniferum* (L.) Schott) is an important aquatic vegetable which belongs to the family Araceae. Its species originated in India/Indonesia and is commonly known as panikachu, pallukabi (Manipur), nalkachu (Assam), lati and kachulati.

Swamp taro [*Colocasia esculenta* var. *stoloniferum* (L.) Schott] is one of the important herbaceous tuber vegetable crops. It is an underutilized but highly productive plant. It grows in flooded, brackish conditions. Swamp taro can be cultivated with minimum effort, and it can sustain growth in waterlogged environment and tolerate brief submergence (Roy Chowdhury et al. 2010). So, this crop is easily cultivated in low-lying areas where other vegetable crops cannot be grown. It is grown primarily as a vegetable food for its edible caudex as well as stolon, but depending on varieties, entire plant parts, viz. leaves, petioles, stolon or runners, are also consumed as green vegetable, especially in states like Assam, Bihar, eastern Uttar Pradesh and West Bengal (Saud and Baruah 2000).

18.5.1 Genetic Resources

About 60 germplasm/genotypes are being maintained at different AICRP on tuber crops of India including 6 at AAU, Jorhat; 42 at BCKV, Kalyani; 1 at IGKV, Jagdalpur; 1 at ICAR-RC NEH, Barapani; 8 at Research Station ICAR-RC, Tripura; and 2 at CAU, Imphal.

Swamp Taro plants with Stolen

18.5.2 Important and Uses

The tubers are the staple carbohydrate foodstuff in many Pacific Islands, where they are eaten boiled, steamed or roasted, sometimes with the addition of coconut milk, or they may be sliced and fried and eaten with sugar. It has been reported that a number of food products are prepared from tubers in the Philippines. The leaves and inflorescence are sometimes eaten as a vegetable.

Component	Quantity
Starch	3.8–7.9%
Sugar	0.77–2.70%
Fat	0.12–0.35%
Crude protein	0.23–0.72%
Vitamin C	40.5–63.7 mg/100 g
Soluble protein	0.20–0.52%

Nutrient Value of Swamp Taro (USDA 2018)

18.5.3 Production

A more or less continuous supply of water is essential, though the plant cannot be grown in streams where the water is running swiftly, or in a fresh marine soil or on a slope where the soil is frequently washed away by heavy rains. It is often grown in coastal swamps just inland of mangrove swamps. It is a perennial crop and planted once a time and then can be harvested for 3–5 years. Before planting, paddling operation is done in the field and planted in 100 × 50 cm spacing. Basal dose of fertilizer @ 80:25:100 kg NPK per hectare is applied for better yield. When Stolon attains 3–4 ft length then it is harvested. Swam Taro yielded 100–150 kg per acre per week in winter, and in summer season, yield of stolon is quite higher, i.e. 150–200 kg per acre per week.

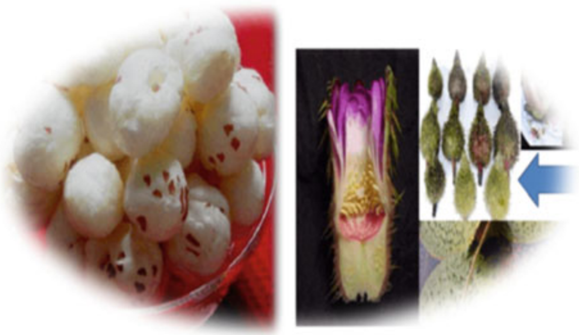
18.6 Makhana

Makhana (*Euryale ferox* Salisb.) is an important aquatic vegetable which belongs to the family Nymphaeaceae. Its species originated in Southeast Asia and China, but is distributed to almost every part of the world and is commonly known as gorgon nut, fox nut and black diamond.

It is an important crop, grown profusely in the stagnant water of wetlands, tanks, ponds, lakes and ditches in the northern parts of Bihar. Besides stagnant water bodies, it is also cultivated in paddy fields and low-lying areas. Makhana plant is considered as a high-value commodity and commercially cultivated only in Bihar as well as certain parts of eastern India. Approximately, 80% of the total production of processed makhana comes from Darbhanga, Madhubani, Purnia and Katihar districts of Bihar. Looking to the importance of this crop a regional centre was set up to conduct research on various aspects of makhana in Darbhanga districts of Bihar under the administrative control of ICAR Research Complex for Eastern Region.

18.6.1 Genetic Resources

First ever variety Swarna Vaidehi is released from ICAR-NRC of Makhana (Darbhanga) through pure-line selection. It has production potential of 2.8–-3.0 tonnes/ha in the farmers' fields, which is almost twofold higher than the traditional cultivars. The Institute Variety Release Committee has approved its release for Bihar, Assam, Chhattisgarh as well as Odisha. Sabour makhana-1 was another important variety developed by BAU, Bihar, having a seed (guri) yield of 32–35 q/ha and pop recovery of 55–60%.



18.6.2 Importance and Uses of Makhana

Makhana or fox nut is a kind of hydrophyte used as both drug and food, which exhibits much application and development prospect in the fields of medicine, food and economy. Makhana possesses high nutritional value and many medical and health protection effects. Popped makhana is one of the most common dry fruits utilized by the people due to low fat content and high contents of carbohydrates, protein and minerals. It is an important aquatic horticultural crop being used as a main ingredient for preparation of various vegetable dishes.

18.6.3 Medicinal Uses of Makhana

It is very popular in Indian (Ayurveda) system of medicine. It is beneficial in the treatment of tridoshas, vata and pitta, beriberi and postnatal weakness in women and also used as an immunostimulant as well as helps to tonify spleen and strengthen kidneys.

Parameters	Raw makhana content	Makhana pop content
Carbohydrate	76.9%	84.9%
Protein	9.7%	9.5%
Fat	0.1%	0.5%
Moisture	12.8%	4.0%
Calorific value (kcal/100 g)	362	328

Source: CSIR (1952)
The quality of makhana protein is very superior to a number of food plant- and animal-based diets

18.6.4 Preparation of Different By-Products of Popped Makhana

Makhana pop is used as a traditional medicine. It is also used in the preparation of delicious and rich sweet dishes like makhana kheer, vermicelli, halwa, puddings and various other dishes like curry, pakoda and snacks. The flour produced from makhana is used as a substitute of arrowroot. The flour is also used as a thickener in different food preparations. Makhana is consumed as a non-cereal food by devotees during their fasts. Hence, it solves the religious purpose. In Hindu religion, it is used in many ceremonies, havan, pooja, etc. In Manipur, makhana is produced for its vegetable purpose also.

18.6.5 Production

Makhana plants germinate from the leftover seeds of the previous season. When makhana is grown for the first time in a new pond, the rate of seed sowing is 80 kg/ha. However, when sowing is done annually, 35 kg of seed is required for 1 ha of water spread. Sprouting takes place by December–January, and the early leaves appear on the pond surface during January–February. During April–May, the entire water surface gets covered with huge, sprawling and thorny leaves, which float on the surface of water. Flowering begins in the month of April when the temperature is around 30 °C, and maximum flowering occurs in the month of May. Makhana flowers stay afloat for 2 days and then submerge inside water. Fruiting begins by mid of May, and each plant bears around 10–20 fruits. Each fruit contains 40–70 seeds, and roughly 100 seeds weigh around 80–100 g. On an average, a plant of makhana yields around 450–700 g of seeds. In local parlance, makhana seeds are called 'guri'. After fruiting, the gigantic leaves are cut and thrown out or left to decay, which enriches the soil health through addition of organic nutrient. The scattered seeds at the bottom of the pond are collected manually during August–September. Harvesting of makhana seeds is done by diving deep inside the water. The process of collection is strenuous involving a thorough sweeping of the entire bottom floor of the water area. Sweeping of the floor, making heaps and their retrieval require several dives inside the water that makes the job really painstaking. Yield of makhana varies normally from 1200 to 1500 kg per hectare. However, in low-depth water bodies, yield varies from 1800 to 2200 kg per hectare.

Harvesting of makhana seeds by 'Gaanja'

18.6.6 Economics of Makhana Cultivation Under Shallow-Pond Cultivation System

The total area under makhana cultivation in India is estimated to be 15,000 ha. It yields 120,000 MT of makhana seeds, which after processing yields 40,000 MT of makhana pop. The estimated value of production at farmers' end is Rs. 250 crore, and it generates a revenue of Rs. 550 crores at traders' level.

Economics per hectare The average seed yield of makhana will 2.6 t/ha if planted in shallow-pond system @ 80 kg seeds per hectare with total input cost of Rs. 77,835. If the seeds are sold at a rate of Rs. 70/kg, total income will be Rs. 182,000. In such case, the net economic return will be Rs. 104,165/ha in a year.

18.6.7 Entrepreneurship and Economic Scope of Popped Makhana

'A way to save Health of Millions and improve Livelihood of Makhana Growers': About five lakh families are directly involved in makhana cultivation, its harvesting, popping and produce selling. About 7500–10,000 tonnes of popped makhana are sold every year from Bihar. The mechanization of makhana popping process will lead to increase in the cultivation area and, thus, the production of makhana seeds will lead to improvement in the livelihood of poor community engaged in makhana cultivation and processing in the very near future. Net profit may be more by adopting mechanized popping as compared to the manual popping method.

18.6.8 Scope of Entrepreneurship by Growing Aquatic Vegetable

- Demand of by-products of aquatic vegetables like makhana, water chestnut flour and lotus root in the urban market is pronouncing day by day due to its nutritional and medicinal properties.
- Neglected water bodies/swampy land can be used for remunerative cultivation of aquatic vegetables.
- By adoption of Integrated approach for growing aquatic vegetables and fruit crops on surrounding bunds and rearing of fish in pond is a sustainable method for higher production and returns per unit area.

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Tropical Tuber Crops: Nutrition and Entrepreneurial Opportunities

19

M. S. Sajeev, G. Padmaja, A. N. Jyothi, T. Krishnakumar, and C. Pradeepika

Abstract

Tropical root and tuber crops are considered as the third important crops after cereals and grain legumes and have important role in food security, nutrition and climate change adaptation. Tuber crops have the highest biological efficiency of all the crops and produce the most dry matter per day per unit area. The high photosynthetic ability of the tuber crops coupled with the tolerance to pests, diseases and drought and adaptability to various agro-ecological zones as well as marginal soils make them ideal crops in developing and less developed nations. The main nutritional value of roots and tubers is attributed to their high energy content, which is approximately one-third of an equivalent weight of grain, such as rice or wheat. Besides being an underground food or energy storehouse, most of the root and tuber crops are also rich in vitamins and minerals. Nutritional disorders resulting from the deficiency of vitamin A, vitamin C and calcium can be easily alleviated by consumption of tuber crops like cassava, sweet potato, yams and aroids. The orange- and yellow-fleshed sweet potato roots and green leaves are good sources of vitamin A, which can prevent night blindness and malnutrition. Sweet potato is also rich in antioxidants such as β-carotene, ascorbic acid and tocopherol (vitamin E), which can prevent coronary disorders and many lifestyle diseases. There is a great variation in the nutritional quality of roots and tubers depending on the variety, location, soil type, agricultural practices, etc.

M. S. Sajeev (✉) · A. N. Jyothi · T. Krishnakumar · C. Pradeepika
ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India

G. Padmaja
ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India

Principal Scientist (Retd), ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India

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Keywords

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19.1 Introduction

Root and tuber crops are important in the sub-Saharan Africa, especially in Nigeria, as they form a major part of the staple food consumed by the populace. In India, tuber crops are cultivated mainly in the Southern, Eastern and North-eastern states, where they play a vital role in alleviating the hunger of a great majority of population. The earlier emphasis on cereals to cope up with the food production calls for a rethinking in view of disproportionate population growth, rapidly shrinking cultivable land and depleting resources. As alternate crops as sources of energy, tuber crops are an inevitable choice. Tuber crops also provide a vast scope for diversification and value addition, offering a great opportunity for non-traditional uses within the country and for exports.

Cassava (*Manihot esculenta Crantz*), sweet potato (*Ipomoea batatas*), taro (*Colocasia esculenta*), yams (*Dioscorea* sp.), elephant-foot yam (*Amorphophallus paeoniifolius*) and arrowroot (*Maranta arundinacea*) are some of the most extensively cultivated tuber crops. Cassava and sweet potato account for about 30% of the total production of root crops in the developing countries. The main nutritional value of roots and tubers lies in their potential ability to provide one of the cheapest sources of dietary energy, in the form of carbohydrates. This energy is about one-third of an equivalent weight of grain, such as rice or wheat, because tubers have high water content. The high yields of most root crops ensure an energy output per hectare per day, which is considerably higher than that of grains. Roots and tubers have many advantages as food crops for household food security, with cassava as possibly the most significant. Besides being a rich source of carbohydrates, most of the root and tuber crops are rich in vitamins and minerals.

19.2 Cassava (*Manihot esculenta Crantz*)

The major biochemical constituent in cassava is starch, which constitutes up to 65–70% of the dry matter. The dry matter content of the tubers varies between 30 and 40%, while the leaves contain ca. 20–28% dry matter. The general biochemical profile of cassava is given in Table 19.1. The tubers have 0.1–0.37% (fwb) crude fibre, and the components of dietary fibre are pectin, hemicellulose, cellulose and lignin as well as non-starch polysaccharides (Holloway et al. 1985). The percentage of fat in tubers is low, ranging from 0.03 to 0.50% (fwb), although variations are likely among cultivars (USDA 2015). Myristic, palmitic, stearic, linoleic and linolenic acids are main constituent fatty acids; however, trace amounts of lauric and palmitoleic acids have also been detected. Tubers with yellow flesh contain beta-carotene (1–70 μg/g dry weight). The consumption of cassava as a sole source of

Table 19.1 Proximate, vitamin and mineral composition of cassava roots and leaves

Principles	Cassava roots	Cassava leaves
Food energy (kcal)	110–149	91.0
Food energy (kJ)	526–611	209–251
Moisture (g)	45.9–85.3	64.8–88.6
Dry weight (g)	29.8–39.3	19–28.3
Protein (g)	0.3–3.5	1.0–10.0
Lipid (g)	0.03–0.5	0.2–2.9
Carbohydrate, total (g)	25.3–35.7	7–18.3
Dietary fibre (g)	0.1–3.7	0.5–10.0
Ash (g)	0.4–1.7	0.7–4.5
Thiamine (mg)	0.03–0.28	0.06–0.31
Riboflavin (mg)	0.03–0.06	0.21–0.74
Niacin (mg)	0.6–1.09	1.3–2.8
Ascorbic acid (mg)	14.950	60–370
Vitamin A (μg)	5.0–35.0	8300–11,800
Calcium (mg)	19–176	34–708
Phosphorus, total (mg)	6–152	27–211
Iron (mg)	0.3–14.0	0.4–8.3
Potassium (%)	0.25 (0.72)	0.35 (1.23)
Magnesium (%)	0.03 (0.08)	0.12 (0.42)
Copper (ppm)	2.00 (6.00)	3.00 (12.0)
Zinc (ppm)	14.00 (41.00)	71.0 (249.0)
Sodium (ppm)	76.00 (213.00)	51.0 (177.0)
Manganese (ppm)	3.00 (10.00)	72.0 (252)

Source: Bradbury and Holloway (1988); Woot-Tsuen et al. (1968); Favier (1977); Lancaster et al. (1982)

protein can result in protein deficiency due to the low level of protein content (0.3–1.0% fresh weight). The roots contain high levels of arginine, glutamic acid and aspartic acid, and ca. 50% of the crude protein in the roots makes up the whole protein, while the rest 50% is free amino acids and non-protein components such as nitrite, nitrate and cyanogenic compounds. The tubers have high levels of lysine and arginine, but cysteine and methionine levels are very low. The calcium content of the roots is high (15 and 35 mg/100 g (fwb)) compared to many other staple crops. The vitamin C (ascorbic acid) content is also high ranging from 15 to 50 mg/100 g edible portions (USDA 2015).

19.3 Sweet Potato (*Ipomoea batatas*)

The starchy roots, nutritionally rich leaves and presence of many vitamins, minerals and functionally active principles make sweet potato a 'superfood'. Carbohydrates, the highest nutrient available in sweet potato roots, constitute about 80–90% of the total dry matter, which ranges from 13 to 48% (Bradbury and Holloway 1988). Generally, the starch content varies from 60 to 70% of the dry matter and total sugars

Table 19.2 Nutritional profile of sweet potato tubers

Parameter	Quantity/100 g edible portion (fwb)[a]	Parameter	Quantity/100 g edible portion (fwb)[a]
Energy	360 kJ (86 kcal)	**Minor nutrients (mg)**	
Major nutrients (g)		Pantothenic acid (B_5)	0.8
Carbohydrates	20.1	Vitamin B_6	0.2
Starch	12.7	Folate (Vit. B_9)	0.011
Sugars	4.2	Vitamin C	2.4
Dietary fibre	3.0	Calcium	30.0
Fat	0.1	Iron	0.6
Protein	1.6	Magnesium	25.0
Minor nutrients (mg)		Phosphorus	47.0
Beta-carotene (orange-fleshed varieties)	8–14	Potassium	337
Thiamine (Vit. B_1)	0.1	Sodium	55
Riboflavin (Vit. B_2)	0.1	Zinc	0.3
Niacin (Vit. B_3)	0.61		

[a]Fresh weight basis. Source: USDA Database (2001)

range from 0.38 to 5.64% (Bradbury and Holloway 1988). Sucrose is the most abundant sugar, followed by glucose and fructose in raw roots. The non-starch polysaccharides comprising cellulose, hemicellulose and pectin contribute towards the ‘dietary fibre’ fraction of sweet potato roots. Shen and Sterling (1981) reported a total dietary fibre content of 7.0% (dwb) in raw sweet potato roots, while 3.0% is reported in other cultivars (USDA 2015) (Table 19.1). The crude protein content in most varieties ranges from 1.3 to 10% (dwb) or 1.6 to 2.2% (fwb). Purcell and Walter Jr. (1980) found that the main amino acids of the non-protein nitrogen fraction were asparagine (61%), aspartic acid (11%), glutamic acid and serine (4% each) and threonine (3%) in ‘Jewel’ sweet potatoes, stored for 107 days. Most of the storage protein in sweet potato is sporamin, accounting for 75–80% of the total protein in roots (Maeshima et al. 1985). The total lipid content in sweet potato roots is in the range of 0.10–0.30% (fwb). The lipid fraction contained 44.7% of linoleic acid and 29.3% of palmitic acid (Opute and Osagie 1978). Sweet potato roots are rich in carotenoids and vitamin C and contain reasonably good amounts of thiamine (B1), riboflavin (B2) and pantothenic acid. Beta-carotene is the most abundant pigment (provitamin A) in sweet potato, and orange-fleshed varieties contain as high as 16 mg/100 g (fwb). It is now recognized as one of the best sources of vitamin A, and the consumption of orange-fleshed sweet potato is promoted as a food-based strategy by FAO, especially in countries and among population, where vitamin A deficiency is a major problem (Table 19.2).

Both the sweet potato leaves and tops are nutritious and are consumed in many parts of the world (Villareal et al. 1979; Woolfe 1992). Besides, the green tops also contain approximately 2.7% crude protein, 20% fibre and 1.7% ash. The leaves of sweet potato variety ‘Suioh’ contained 117 mg Ca, 1.8 mg iron, 3.5 mg carotene, 7.2 mg vitamin C, 1.6 mg vitamin E and 0.56 mg vitamin K per 100 g fresh weight (Ishiguro et al. 2004).

19.4 Yams (*Dioscorea* sp.)

The edible species of yams are *D. alata, D. esculenta* and *D. rotundata*. Dry matter content varies from 32 to 44%, and starch constitutes the major carbohydrate in all the three species ranging from 51 to 90% of dry matter. Apart from the major ingredients such as starch, they are also rich in various minerals and dietary fibre. Eka (1985) reported that the potassium content of yam (*D. alata*) was high and hence the tubers were suited for people having hypertension, but not for people suffering from renal failure. Tubers are also rich in dietary fibre, which confers many health attributes to it (Muzac-Tucker et al. 1993) (Table 19.1). The main sugars in yams include glucose and sucrose, and during storage, formation of maltose and fructose was also observed (Kouassi et al. 1990; Hariprakash and Nambisan 1996). The fat content is generally low in tubers (1–3% fwb), protein content varies between 6 and 8% and arginine is the major amino acid. Holloway et al. (1985) reported pectin, hemicelluloses, cellulose and lignin contents of 2.6%, 3.4%, 1.6% and 1.1%, respectively, in *D. alata* tubers, and the former three contribute towards dietary fibre in tubers. *D. alata* tubers are rich in potassium and iron. Tubers contain mucilage (2.5% in *D. esculenta*, 1.4% in *D. alata* and 2% in *D. rotundata*), which is mainly composed of glycoproteins (Table 19.3).

Table 19.3 Nutritional profile of edible yam (*Dioscorea* spp.) expressed per 100 g fresh weight

Parameters	*D. alata*	*D. rotundata*	*D. esculenta*
Major nutrients (g/100 g fwb)			
Total carbohydrate	22–31	15–23	17–25
Starch	16.7–28	26.8–30.2	25
Free sugars	0.5–1.4	0.3–1	0.6
Crude protein	1.1–3.1	1.1–2.3	1.3–1.9
Crude fat	<0.1–0.6	0.05–0.1	0.04–0.3
Crude fibre	1.4–3.8	1.0–1.7	0.2–1.5
Ash	0.7–2.1	0.7–2.6	0.5–1.5
Energy (kcal)	140	142	112
Minerals and vitamins (mg/100 g fwb)			
Phosphorus	28–52	17	35–53
Calcium	28–38	36	12–62
Iron	5.5–11.6	5.2	0.8
Vitamin C	–	2.0–8.2	6.0–12.0
Thiamine	0.05–0.10	–	0.1
Riboflavin	0.03–0.04	–	0.01
Niacin	0.5	–	0.8

Source: Asiedu et al. (1997); Bradbury and Holloway (1988); Coursey (1967); Eka (1985); Muzac-Tucker et al. (1993) and Opara (1999); – indicates non-availability of data

19.5 Taro (*Colocasia esculenta*)

Starch is the major component of taro (70–80% dwb) followed by protein (ca. 11% dwb) (Njintang et al. 2007), while cultivar variations are common (Table 19.1). The protein fraction is reported to be rich in essential amino acids, except lysine (Arnavid-vinas and Lorenz 1999). The fine nature of starch granules imparts hypo-allergenic property to taro starch (Jane et al. 1992). The amylose:amylopectin ratio is 1:7 and is different from the other tuber starches, which is usually 1:4 (Temesgen and Retta 2015). The important sugars are sucrose, fructose, maltose, glucose and raffinose, while the major organic acids are malic acid, citric acid and oxalic acid (Arnavid-vinas and Lorenz 1999). Taro is a low-fat food as the fat content ranges from 0.1 to 0.2% (Onwueme 1999). Nip (1997) reported that taro tubers contained total soluble and insoluble dietary fibres in the range of 5.02–9.01%, while much lower levels of crude fibre (0.3–3.8%) were reported in the taro cultivars from Cameroon (FAO 1999). Several workers have reported that taro tuber is a rich source of minerals such as iron, calcium and potassium and low in sodium (Temesgen and Retta 2015; USDA 2015). A high potassium-to-sodium ratio is advantageous for hypertensive patients (Temesgen and Retta 2015). Although the tubers are low in vitamins, the leaves of taro, which are widely consumed as a vegetable in many places, are a rich source of beta-carotene, iron and folic acid (Onwueme 1999) (Table 19.4).

19.6 Tannia (*Xanthosoma sagittifolium*)

Although tannia (*Xanthosoma sagittifolium*) has its origin in South America and the Caribbean, it got subsequent acceptance as a staple diet of several countries in the America, West Africa, Asia and the Pacific. Tannia corms contain 70–80% water, and starch content ranges between 22 and 40% (Agbor-Egbe and Rickard 1990) with variable concentrations of nutrients. The approximate composition of tannia corm on a fresh weight basis is presented in Table 19.1, and the tubers are high in potassium, zinc and nicotinic acid compared to other edible aroids (Bradbury and Holloway 1988). The leaves are known to contain reasonably high levels of antioxidants, vitamins and dietary fibre (Ekwe et al. 2009).

19.7 Elephant-Foot Yam (*Amorphophallus paeoniifolius*)

The elephant-foot yam (*Amorphophallus paeoniifolius*), besides being used as a nutritionally rich vegetable, with its medicinal and health benefits, finds use in Ayurvedic medicinal preparations (Angayarkanni et al. 2010). Generally, the roots are low in energy and fat contents (80–135 kcal/100 g and 0.09–0.28 g/100 g fwb, respectively). Basu et al. (2014) reported high protein (9.81% dwb), fibre (5.7% dwb) and ash (4.83% dwb) content in the edible tuber. Furthermore, high contents of vitamin C (76.65 mg/100 g dwb) and α-tocopherol (vitamin E; 900 mg/100 g dwb),

Table 19.4 Nutrition value of taro (*Colocasia esculenta (L.) Schott*) tubers (per 100 g fwb)

Principles	Nutrient value		
	USDA (2003)	Hedges and Lister (2006)	Onwueme (1999)
Energy (kcal)	112	114	–
Major nutrients (g)			
Carbohydrates	26.46	26.80	13–29
Protein	1.50	1.34	1.4–3.0
Total fat	0.20	0.11	0.16–0.36
Dietary fibre	4.1	2.50	–
Ash	–	1.91	0.6–1.3
Vitamins (µg)			
Folates	22		
Niacin	600	780	900
Riboflavin	25	29	40
Thiamine	95	28	180
Vitamin A	12	6	–
Vitamin C	4500	14,300	700–900
Electrolytes (mg)			
Sodium	11	4.2	–
Potassium	591	489	–
Minerals (mg)			
Calcium	43	20.3	–
Iron	0.55	0.44	–
Zinc	0.23	2.06	–

both possessing antioxidant activity, were also reported. Minerals such as potassium, calcium, magnesium and zinc were also reported to be high in this variety, although lower values of potassium and magnesium (Table 19.1) have also been reported indicating the high varietal variations (Chattopadhyay et al. 2009). Koni et al. (2017) observed high protein and fat contents (1.13% and 1.17%, respectively, on dry weight basis), besides very high calcium (850 mg/100 g) and magnesium (151 mg/100 g). Srivastava et al. (2014) reported very high contents of crude fibre and protein and low content of fat in the tuber in addition to high amount of iron (340 mg/kg dwb) and magnesium (119 mg/kg dwb). The low fat content, coupled with high fibre and protein, could make elephant-foot yam a healthy and nutritious tuber for human consumption (Table 19.5).

19.8 Minor Root Crops

Apart from the major tropical tuber crops, there are some minor crops which are cultivated in small pockets in many parts of the world. Two of these which have nutritional potential are Chinese potato (*Solenostemon rotundifolius*) and arrowroot (*Maranta arundinacea*). Chinese potato tubers are rich in energy, and the

Table 19.5 Nutritional profile of elephant-foot yam and tannia tubers (100 g dwb)

Principles	Elephant foot yam[a]	Tannia[b]
Major nutrients (g)		
Carbohydrates	70.75	93.62
Protein	11.53	2.83
Fat	3.52	0.93
Crude fibre	14.32	0.88
Ash	6.90	1.74
Minor nutrients (mg)		
Potassium	3.81	525
Zinc	2.31	0.46
Sodium	–	66
Iron	34.02	0.42

[a] Source: Srivastava et al. (2014); Basu et al. (2014)
[b] Akpan and Umoh (2004)

Table 19.6 Nutrient content of Chinese potato, *vis-à-vis* potato[a]

Component/100 g fwb	Potato	Chinese potato
Energy (kJ)	322	394
Protein (g)	2.0	1.3
Fat (g)	0.09	0.20
Carbohydrate (g)	17	21
Fibre (g)	2.2	1.1
Sugar (g)	0.78	–
Calcium (mg)	12	17
Vitamin C (mg)	19.7	1.0
Thiamine (mg)	0.08	0.05
Iron (mg)	0.78	6.0

[a]Source: Enyiukwu et al. (2014)

carbohydrate content is comparable to sweet potatoes or potatoes. Besides, the tuber is also reported to contain several amino acids such as arginine, aspartic acid and glutamic acid and minerals such as calcium and iron (Schoeninger et al. 2000). Arrowroot (*Maranta arundinacea*) is an under-exploited tuber crop having tremendous potential in food and pharmaceutical industries. The tubers contain about 10–25% extractable starch, which, from a nutritional point of view, is the richest natural starch on the earth, and the amylose content in starch ranges between 16 and 27% (Spennemann 1992) (Table 19.6).

19.9 Functional and Nutraceutical Qualities

19.9.1 Sweet Potato

Sweet potato is increasingly recognized worldwide as a healthy food, due to several of its nutraceutical components, viz. dietary fibre, vitamin A, vitamin C, anthocyanins and xanthophylls. The roots are highly functional, low-calorie food, with anti-diabetic effects (Kusano and Abe 2000). The anti-diabetic activity has been attributed to its ability to stabilize blood sugar levels and lower insulin resistance. Mohanraj and Sivasankar (2014) demonstrated that the carbohydrates from sweet potato stabilized the sugar levels in blood and decreased the resistance to insulin. Most of the yellow- and orange-fleshed varieties of sweet potato contain beta-carotene, the precursor of vitamin A, which also possesses antioxidant activity. Vitamin C also contributes to the antioxidant activity of the roots. High content of vitamin B_6 (pyridoxine) in the roots helps in reducing the blood levels of homocysteine, which is associated with the increased risk of cardiovascular diseases.

Purple-fleshed sweet potatoes are a rich source of anthocyanins, which have medicinal value as antioxidant and cancer-preventing agent. Besides, in Japan, the coloured roots are used for extracting the pigment, which is further used in various food products. Suda et al. (2003) reported that sweet potato anthocyanins have multiple physiological functions such as radical scavenging, anti-mutagenic, hepato-protective, anti-hypertensive and hypoglycaemic activities.

Sweet potato cultivar ‘Ayamurasaki’ (purple fleshed) has high angiotensin-converting enzyme (ACE)-inhibitory activity compared to the white- or orange-fleshed sweet potatoes (Yamakawa et al. 1998). Oki et al. (2002) found that anthocyanins possess major radical scavenging activity in the cultivars, viz. ‘Ayamurasaki’ and ‘Kyushu-132’, while in the cultivars, viz. ‘Miyanou 36’ and ‘Bise’, the phenolic compounds such as chlorogenic acid were responsible for the major radical scavenging activity. These researchers also found that the peonidin aglycon-containing anthocyanins had more radical scavenging effect than the cyanidin aglycon-containing ones. The chemical structures of two major anthocyanins from purple-fleshed sweet potato were established by Odake et al. (1992) as YGM 1a, YGM 1b, YGM2, YGM3, YGM4b, YGM5a, YGM5b and YGM6, of which the first four belonged to the cyanidin type and the latter four belonged to the peonidin type. Suda et al. (2003) reported nine anthocyanin pigment peaks by HPLC in the sweet potato variety Yamagawa murasaki and 13 peaks in the Tanegashima murasaki variety. Terahara et al. (1999) isolated eight acylated anthocyanins from the purple-fleshed sweet potato variety ‘Yamagawa murasaki’. The purple-fleshed sweet potato juice with high anthocyanin content has been reported to have ameliorative effect on the carbon tetrachloride-induced liver injury (Suda et al. 2003). The anti-hyperglycaemic effect of diacylated anthocyanin from ‘Ayamurasaki’ was reported to be due to the α-glucosidase inhibitory action (Matsui et al. 2002).

Sweet potato leaves are also a rich source of nutraceuticals. Ishiguro and Yoshimoto (2005) reported high content of polyphenols and xanthophylls in sweet potato leaves. They reported the presence of high concentration of lutein, a member of the xanthophyll family of carotenoids, in sweet potato leaves (variety 'Sujoh'). Lutein was present to the extent of 29.5 mg/100 g (fwb), and hence the consumption of leaves of this variety was capable of mitigating eye diseases like age-related macular degeneration and cataract. Huang et al. (2004) reported that the sweet potato leaves contained high amounts of total phenolic and flavonoid compounds, which were responsible for its DPPH radical scavenging activity.

Although the anti-mutagenic effect of purple-coloured sweet potatoes was due to the cyanidin type of anthocyanins, in the yellow-, white- and orange-fleshed varieties, phenolic compounds contributed to the anti-mutagenic effect of the outer portions (Yoshimoto et al. 2003). Thompson (1981) isolated and separated four isomers of caffeoylquinic acid from 14 sweet potato cultivars. Truong et al. (2007) characterized the phenolic acids of sweet potato roots and leaves and found that chlorogenic acid was the major phenolic acid in the roots, while 3,5-di-*o*-caffeoylquinic acid and 4,5-di-*o*-caffeoylquinic acid were the major compounds in sweet potato leaves. The sweet potato leaf phenolics were also characterized by Islam (2006), who found that caffeoylquinic acid (CQA) derivatives and caffeic acid were the major polyphenolics. Of these, caffeic acid and 3,4,5-tri-caffeoylquinic acid exhibited very high depression of melanin production and the action was through the potent inhibition of tyrosinase activity.

19.9.2 Yams and Elephant-Foot Yam

Dioscorin, the main storage protein found in tropical *Dioscorea* tubers, is reported to possess carbonic anhydrase and trypsin inhibitor activities. Dioscorin from the fresh tubers of *D. batatas* exhibited DPPH radical scavenging activity (Hou et al. 2001) and also showed beneficial effects in lowering blood pressure. Dioscorin was also reported to have angiotensin-converting enzyme (ACE) inhibitor and anti-hypertensive activities on spontaneously hypertensive rats (Hsu et al. 2002).

The various medicinal properties of elephant-foot yam have been extensively studied, which include gastroprotective, analgesic, antibacterial, anti-inflammatory, antioxidant and hepato-protective activities (Nataraj et al. 2009; De et al. 2010). The presence of antioxidant vitamins such as vitamin C and vitamin E could further enhance the health value of elephant-foot yam tubers (Basu et al. 2014). Tubers had high levels of vitamin C (76.65 mg/100 g dwb) and α-tocopherol (vitamin E; 900 mg/100 g dwb), both possessing antioxidant activity. The tubers are especially rich in zinc (Basu et al. 2014; Srivastava et al. 2014) containing 2.0–2.3 mg/100 g as against a recommended dietary intake of 0.015 mg. Zinc is an essential component of more than 300 enzymes in the human body, which participate in the synthesis and catabolism of carbohydrates, lipids, proteins and nucleic acids. Phytochemical screening of the aqueous extract of elephant-foot yam showed the presence of flavonoids and tannins contributing to health effects (Dey and Ghosh 2010). Quercetin was a major flavonoid isolated and characterized from elephant-foot yam, which has reported antioxidant activity (Nataraj et al. 2009). Bhandari and Kawabata

(2004) analysed the phenolic and antioxidant activity of four wild yam (*Dioscorea* spp.) tubers available in Nepal and found that the total polyphenol content ranged from 13 to 166 mg/100 g FW, and the wild tubers also possessed significant antioxidant activities.

19.9.3 Taro

Yellow-fleshed roots and young tender leaves of taro have significant levels of phenolic flavonoid pigments and antioxidants such as β-carotenes and cryptoxanthin along with vitamin A. One hundred grams of fresh taro leaves provide 4825 IU or 161% of RDA of vitamin A. These compounds are required for maintaining healthy mucus membranes, skin and vision. A high potassium-to-sodium ratio in tubers is advantageous for hypertensive patients (Temesgen and Retta 2015). Although the tubers are low in vitamins, the leaves of taro, which are widely consumed as a vegetable in many places, are a rich source of beta-carotene, iron and folic acid (FAO 1999). Yellow-fleshed cultivars of taro are rich in phenolic compounds possessing antioxidant activity. The mucilage component of taro, although considered disadvantageous during processing, is a complex mixture of neutral polysaccharides, along with some fibre and protein (Nip 1997). Nevertheless, Hollyer et al. (1997) reported that the mucilage was important from the health point of view, imparting properties such as slow transit of food through upper GI tract, holding moisture to prevent constipation and lowering blood cholesterol by binding bile.

19.9.4 Minor Root Crops

Chinese potato tubers possess flavour and have medicinal properties due to the high content of flavonoids, which could lower blood cholesterol as well as possess high antioxidant activity (Sandhya and Vijayalakshmi 2005). Arrowroot starch is popular for its high digestibility and medicinal properties. It possesses demulcent properties that soothe and protect irritated or inflamed internal tissues of the body and hence is given in bowel complaints (Mathew 2007). Arrowroot is used as an article of diet in the form of biscuits, puddings, jellies, cakes, hot sauces, etc. and an easily digestible food for children and people with dietary restrictions (Spennemann 1992). The lack of gluten in arrowroot starch makes it ideal as a replacement for wheat flour in baking.

19.10 Anti-nutritional Principles in Root Crops

19.10.1 Cyanide in Cassava

Cassava leaves and tubers contain cyanogenic glucosides, viz. linamarin (93%) and lotaustralin (7%), which release free hydrogen cyanide during processing. Cassava cultivars are classified as 'bitter' or 'sweet' depending on the level of cyanogenic glucoside, and values from 15 to 400 mg of hydrogen cyanide per kilogram of fresh weight of cassava roots have been reported for bitter varieties. Sweet varieties of cassava (low cyanide content) will typically contain approximately 15–50 mg hydrogen cyanide/kg fresh cassava. Sweet varieties of cassava can be processed adequately by peeling and roasting, baking or boiling, while bitter varieties of cassava (high cyanide content) require more extensive processing such as drying and fermentation. The World Health Organization (WHO) has set the safe level of cyanogens in cassava flour at 10 ppm or 10 mg HCN/kg, while in Indonesia, the acceptable limit is 40 ppm (Cardoso et al. 2005; Djazuli and Bradbury 1999). Traditional methods of cooking, chipping and drying, parboiling and drying, etc. reduce the glucoside content to safe levels, although bitter varieties require much rigorous processing methods such as fermentation. The most effective way of detoxifying is grinding followed by sun drying, while fermentation helps to eliminate cyanoglucosides as a result of assimilation by the microorganisms (Padmaja 1995). The amount of cyanogenic glucosides varies with the part of the plant, its age, variety and environmental conditions such as soil, moisture and temperature. Certain varieties of cassava have long been designated as sweet or bitter, purportedly in relation to their cyanogenic glucoside content. The sweet varieties are supposed to be much lower in HCN content than the bitter varieties.

19.10.2 Enzyme Inhibitors in Sweet Potato

Proteinaceous inhibitors of digestive enzymes are present in many food crops. Two types of enzyme inhibitors, viz. proteinase inhibitors and amylase inhibitors, are ubiquitous in occurrence in several cereal and legumes, and many have been characterized. Sohonie and Bhandarkar (1954) isolated a highly thermolabile protein from sweet potato roots. Subsequently, three trypsin inhibitors were isolated from sweet potato roots by Sugiura et al. (1973). They reported molecular weights of 23,000 and 24,000 for two isoinhibitors II and III, respectively. Obidairo and Akpochafo (1984) isolated several smaller molecular weight inhibitors from local Nigerian cultivars. Seven trypsin isoinhibitors were characterized from American sweet potato cultivars by Dickey and Collins (1984). Sugiura et al. (1973) reported loss in trypsin inhibitor activity, when the arginyl groups were modified and hence suggested that arginine was essential for the activity. Traces of chymotrypsin inhibitor activity were first reported in sweet potato roots by Bradbury et al. (1985). Sasikiran (2000) isolated four trypsin isoinhibitors from five accessions of sweet potato. Of the four isoinhibitors, SPI_2, SPI_3 and SPI_4 had high T1 activity, while SPI_1 had prominent chymotrypsin inhibitor activity. Sweet potato roots also have been reported to contain α-amylase inhibitors (Rekha 2000). Four isoinhibitors could be purified from sweet potato by ammonium sulphate precipitation and a two-step ion-exchange chromatography on DEAE cellulose.

19.10.3 Other Root Crops

Oxalates are one of the major limiting factors in the utilization of taro and elephant-foot yam as they impart acrid taste or cause irritation when raw or partially processed tubers are eaten. Acridity is experienced as irritating (itching/stinging/burning) sensation in the mouth and throat, which is followed by swelling and inflammation of the region. Rubbing of certain varieties on external skin may also cause itching, thus indicating the intensity of irritation. Although acridity is believed to be caused by needle-like calcium oxalate crystals, raphides that can penetrate soft skin and cause irritation (Bradbury and Nixon 1998), latest reports also correlate it with the presence of protease in the tubers that helps to digest the surface proteins of mouth and throat (Bradbury and Hammer 1990). Localization studies showed that acridity of taro is concentrated mostly in the outer layers of the corm and could be largely removed by peeling off a thick layer followed by prolonged boiling (Quach et al. 2003). Oxalates also are reported to chelate with minerals such as iron, calcium, zinc and magnesium unavailable to body. The crystals of oxalates can also get deposited in kidney and cause renal stones, leading to renal failure. About 75% of kidney stones are composed of oxalates, and consumption of foods containing oxalate increases urinary oxalate content (Williams and Wandzilak 1989).

Another group of antinutrient factors present in taro is the enzyme (protease and amylase) inhibitors. Alpha-amylase inhibitors were isolated and characterized from several root crops such as taro and yams (Rekha 2000). Among the four amylase isoinhibitors from taro, SAI_1 was found to be a high molecular protein (63 K Da), comprised of three subunits of 21 K Da each. The other three isoinhibitors had molecular weight in the range of 14–20 K Da. Lysine and disulphide linkages were essential for the AI activity. SAI_1 and SAI_2 were resistant to pepsin, trypsin and chymotrypsin (Rekha 2000).

19.11 Processing-Related Changes in Quality of Root Crops

Many processed products are available from all the root crops, which include primary processed food products such as flour or fried chips and secondary products such as fortified foods, baked items, pasta and noodles. Studies related to only primary food products are included in this chapter due to the extensive information available on the other products.

19.11.1 Cassava

Aniedu and Omodamiro (2012) studied the effect of three different drying procedures on the nutritional quality of high-quality cassava flour, viz. (1) sun drying at an average temperature of 34 °C and relative humidity of 80% for 10 h, (2) drying in a cabinet dryer at 60 °C for 8 h and (3) flash drying at 120 °C for 30-s residence time. They found that drying methods had significant influence on the nutritional quality of the flours, except on HCN, pH, titratable acidity, reddish colour, loose density and water-absorption capacity. The higher temperature short-time (flash drying) method resulted in higher retention of total carotenoid and beta-carotene contents as well as the yellowish colour, while the lowest retentions were obtained in sun drying. Therefore, sun drying method may not be an adequate method in producing cassava flour from yellow-fleshed roots. Drying methods also influence the proximate composition of cassava flour. Significantly higher levels of protein, fat and fibre were retained in flash-dried flour compared to cabinet or sun drying (Odunola and Adekunle 2017). Samad et al. (2018) compared the chemical characteristics of high-quality cassava flour (HQCF) from four local varieties, such as jame-jame cassava, yellow cassava, digol cassava and butter cassava. The cyanogen content ranged between 24.4 and 48.5 ppm, protein content ranged from 1.3 to 2.0%, crude fat content was between 0.3 and 0.5% and carbohydrate content ranged from 83.2 to 85.5%. Generally, drying is not considered an efficient means of detoxification, especially for cassava varieties with high initial cyanogen glucoside content, and in Tanzania, sun drying whole roots into *makopa* was found to reduce the cyanide levels from 751 to 254 mg HCN equivalents/kg DW. Thinner cassava pieces dry faster, and since water is an essential substrate for linamarase action, cyanogenic glucoside removal ceases (Mlingi and Bainbridge 1994). The effect of various processing methods in eliminating cyanogens from cassava was studied by Nambisan (1994). It was reported that up to 80% of the glucosides was removed by boiling and sun drying, while only about 20% was eliminated by frying, baking and steaming. Crushing and pounding fresh roots followed by sun drying eliminated as high as 95% of the cyanogens, while boiling of leaves removed about 85% of the cyanogenic glucosides.

19.11.2 Sweet Potato

Sweet potato flour can be promoted as a substitute for wheat flour in many baked products owing to its high carotenoid content imparting functional value to the products. Nevertheless, it must be price competitive with wheat flour and the product should be of good quality. Ruttarattanamongkol et al. (2016) investigated the influence of drying methods on physico-chemical properties and retention of anthocyanin, β-carotene and antioxidant activity of purple- and orange-fleshed SP flours. Peeled purple and OFSPs were pretreated by blanching (100 °C, 5 s) and soaking in 0.5% (w/v) sodium metabisulphite, followed by either drying in hot-air oven at 50–80 °C or steaming for 10 min followed by drum drying at 80–110 °C and

3–7 rpm drum speed. Although the drying processes significantly enhanced the anthocyanin contents of flour by 1.8–3.8 times, there was a significant loss of β-carotene. Drum drying yielded flour with good colour, higher total phenolic contents and antioxidant activity than hot-air drying. The optimal conditions for drum-dried and hot-air dried flour were 95 °C at 5 rpm and 70 °C.

The content of various carbohydrate fractions in raw and baked sweet potatoes (variety 'Garnet') has been worked out by Shen and Sterling (1981), who found that baking led to sharp increase in sugars from 22.4% (dwb) to 37.6%. The carotenoid retention in boiled and mashed orange-fleshed sweet potato (OFSP) was investigated by Jaarsveld et al. (2006). As high as 92% retention was observed when the OFSP roots covered with water were boiled for 20 min. Loss increased with cooking time. Dincer et al. (2011) compared the effect of baking or boiling on the nutritional and antioxidant properties of sweet potato and found that the protein and starch were significantly reduced during boiling with greater loss of the latter. Beta-carotene contents were considerably reduced in baked roots than boiled roots. Vimala et al. (2011) studied the retention of carotenoids during processing of OFSP, and the highest retention was observed in oven drying followed by boiling and frying, while sun drying led to maximum loss.

The effect of various processing methods such as oven drying, cooking and microwave baking on the removal of trypsin inhibitors from sweet potato was studied by Sasikiran (2000), and it was found that between 80 and 90% trypsin inhibitor (TI) activity was retained in sweet potato chips up to 2 h at 70 °C. Heating at 100 °C led to rapid inactivation of TI of sweet potatoes. Between 17 and 31% TI activity was retained in cooked tuber pieces of sweet potatoes, and very effective inactivation of trypsin inhibitors of sweet potatoes could be obtained through microwave baking.

The amylase inhibitors of sweet potato were completely inactivated after 4 h at 90 °C. Cooking for 30 min did not completely inactivate the AI of sweet potato, and around 19–30% retention of AI activity was reported in roots after microwave baking (Rekha 2000). Flour preparation after grating and drying was the best method to almost completely eliminate the AI activity.

19.11.3 Other Root and Tuber Crops

Goly N'dri et al. (2018) studied the effect of boiling on the proximate principles in lesser yam (*Dioscorea esculenta*) tubers and reported that the crude protein contents (5.68%), ash (2.33%), crude fibre (5.02%) and crude fat (0.61%) were significantly lowered in the boiled tubers while the carbohydrate (83.03%) and total and reducing sugars (13.45% and 5.16%), respectively, significantly increased in the boiled tubers. The antinutrients such as phytate (280.76%), alkaloids (43.66%), oxalate (12.89%) and tannins (5.80%) were significantly reduced in the boiled tubers. Adegunwa et al. (2011) compared the effect of fresh sun/oven drying, boiling and roasting or roasting and drying on the nutritional components of *D. alata* and taro tubers and found that oven drying and fresh sun drying were better processing methods than others in retaining nutrients. Effects of three methods of cooking such as boiling, steaming and baking on the nutrient and antinutrient contents of tubers of *Dioscorea alata* and *D. esculenta* were investigated by Wanasundera and Ravindran (1992), who found that the crude protein contents of the tubers mildly decreased with cooking, while the crude fat, crude fibre, starch and total sugar contents were unaffected by cooking. Water-soluble minerals leached out during boiling, leading to a reduction in the ash content of boiled tubers. Boiling resulted in greater loss of oxalates (40–50%) compared to steaming (20–25%) and baking (12–15%). Obadina et al. (2014) studied the effect of soaking pretreatments on some of the properties of flour obtained from two varieties of yam, viz. *Dioscorea alata* and *Dioscorea rotundata*, after pretreatments such as washing, chipping and parboiling at 50 °C followed by soaking for 18 h, drying at 60 °C and milling to flour. The protein content of 18-h-soaked *D. rotundata and D. alata* flour samples was significantly reduced, while soaking had no effect on the fat and ash content.

Generally, taro α-amylase inhibitors were more heat labile than sweet potato inhibitors. In comparison to cooking by boiling in water, microwave baking was a much better method for the inactivation of the α-amylase inhibitor of taro (Rekha 2000). Processing-related changes in acridity factors were studied by Osisiogu et al. (1974), who found reduction in the irritant effect of tannia after boiling for 15 min and complete disappearance after 1-h boiling. Wanasundera and Ravindran (1992) reported 40–50% reduction in total oxalates in yam tubers (*Dioscorea alata* and *D. esculenta*) upon boiling. Iwuoha and Kalu (1995) also found boiling to cause significant reduction in oxalate content of *Colocasia esculenta* and *Xanthosoma sagittifolium*. Catherwood et al. (2007) reported 64–77% reduction in total oxalate levels of four different cultivars of Japanese taro by boiling.

19.12 Value-Added Products for Entrepreneurship Development

Tuber crops though branded as poor man's crops has lot of unrealized potential to be used in food and industrial applications. They can be converted to chips and other fried food items, which could fetch market in rural and urban areas. The high-end functional pasta and noodles with its low cooking time, slow digestibility and high functional value are good alternate food to the time-pressurized consumers, especially in urban areas. Among the various industrial products, scope for the biodegradable packaging material as an alternate to synthetic polymer-based materials is enormous. Cassava is included in the national biofuel policy of our country, and the novel technology for the production of biofuels from cassava starch and starch factory by-products gives ample opportunities when the availability of other conventional sources will be a problem. There is a vast scope for modified starches in various food and industrial applications: superabsorbent gel for healthcare and agricultural fields, natural colourant from sweet potato and yams, cassava starch-based nanocomposites for sustained- and slow-release drug delivery, cassava starch-based corrugating adhesives, cassava starch graft *co*-polymers in oil drilling, sizing and printing of cotton fabrics and water treatment. The non-edible part of cassava plant can also be commercially exploited, viz. for the production of particle boards from stems. Thus, tuber crops with their present status as a subsistence or livelihood security crops can effectively be transformed to high-value commercial crops, provided that innovative technologies are explored and applied for their post-harvest management and value addition.

19.13 Novel Food Products

Tuber crops are important sources of starch after cereals, besides being used as staple or supplementary food. Cassava and sweet potato are the most important among the tuber crops, and other tubers are grown as vegetable crops on homestead or semi-commercial scale. The perishable nature of tropical tuber crops and the difficulties in long-distance transport, storage and marketing constitute major problems for farmers. In order to overcome these problems, processing, value addition and product diversification of tubers on the production catchment itself are recommended. Besides serving as an insurance crop during times of food scarcity, it can also function as an industrial raw material for a wide spectrum of products. Tuber crops, though branded as poor man's crops in rural areas, have considerable unrealized potential for processing into high-end products for food, feed and industrial uses. Agro-industrial transformation of these crops by linking improved production and processing technologies, marketing techniques and institutional innovation in processing technologies ensures food security, rural employment and adequate remuneration to the producers. ICAR-Central Tuber Crops Research Institute under Indian Council of Agricultural Research is a pioneer in the R&D activities of tropical tuber crops and has developed an array of novel value-added products from tuber crops suited to the food and industrial sectors. This chapter provides a comprehensive knowledge on the innovative technologies available for the value addition of tropical tuber crops for the food and industrial sectors.

19.13.1 Cassava Porridge and Rava

Cassava or tapioca is one of the important tuber crops, valued for its high starch content (20–35%). Cassava rava is a pre-gelatinized granular product similar to wheat semolina and finds use as a breakfast recipe product. The tubers after peeling are sliced into round chips and partially cooked in boiling water for 5 min; the parboiled pieces are sun dried and powdered coarsely using a hammer mill. The fine fraction obtained during sieving can be converted into porridge powder by flavouring with sugar, cardamom and fried powdered cashew nuts. The residue is sieved through larger mesh size sieve to obtain rava.

19.13.2 Protein- and Fibre-Enriched Functional Foods

The cost of making value-added snack foods from cassava could be considerably reduced, if wet cassava paste is used instead of cassava flour. Such an innovation was made in making a highly acceptable crisp snack food, viz. *chitchore* from cassava. The wet cassava tuber paste is mixed with ingredients like maida, cheese, salt, sugar, baking powder and white pepper. The dough, after proofing for 1 h, is spread into sheets, cut into small discs of 1 cm diameter and deep-fried in oil.

Mini-papads were developed from cassava flour by adding functional ingredients, viz. fibre sources (wheat bran, oatmeal, rice bran and cassava fibrous residue) or protein sources (cheese, defatted soy flour, prawn powder and whey protein concentrate). The fibre/protein sources are added to gelatinized cassava slurry and mixed thoroughly. The spicy condiments are also added and spread on plastic sheets, which are then dried in the sun for 36 h. The papads are peeled off from the sheets and packed. The deep-fried products have soft and crispy texture.

19.13.3 Fried Cassava Chips and Snack Foods

Fried cassava chips presently available in the market are often too hard to bite and bear no comparison with potato chips, leading to poor acceptability of the product and lower price. However, excellent quality fried chips can be made from cassava tubers by soaking the chips in acetic acid-brine solution for 1 h, parboiling for 5 min, surface drying and deep-frying in oil. This facilitates the removal of excess starch and sugars from the cassava slices, with the result that light-yellow crispy chips can be obtained, having soft mouth feel and good texture.

Variety of snack foods having good texture and taste can be prepared from cassava-based composite flour containing maida, Bengal gram flour, rice flour, salt, chilli powder, asafoetida, baking soda and oil. The ingredients are thoroughly mixed and made into dough with hot water, proofed for 1 h and then extruded through hand extruder or snack food-making machine with suitable dies into hot oil. The ready-to-eat fried snack foods include cassava pakkavada, sweet fries, nutrichips, crisps, salty dimons, hot sticks, salty fries, sweet dimon, murukku, etc.

19.13.4 Vacuum-Fried Chips

Vacuum-fried chips were developed from orange- and purple-fleshed sweet potato tubers. The oil retention was 50.30% lower in the vacuum-fried chips of orange-fleshed sweet potatoes, than that of atmospheric fried chips where the retention of carotenoids was also higher (6.81 mg/g). In purple-fleshed sweet potato vacuum-fried chips, the oil retention was 60% lower and retention of anthocyanins was higher.

19.13.5 Bakery Products

Protein- and fibre-enriched gluten-free functional cookies from orange- and purple-fleshed sweet potato were developed using whey protein concentrate, fructo-oligosaccharide, maltodextrin and sucralose with 8.02% protein, 10.33% fibre and 411 kcal/100 g. Also, they are rich in bio-functional components such as total phenols, total flavonoids, total carotenoids and anthocyanin content. The bread made from orange-fleshed sweet potato with 9% whey protein concentrate and 6% psyllium husk has 17.72% protein, 52.58 EGI and 3.78 mg/100 g carotenoids. Taro flour-based gluten-free cookies were produced with rice flour, sorghum flour and cassava flour. Protein-rich sweet potato-based muffins with 7.5% protein and 2.5% crude fibre were developed using 47% sweet potato flour, 03% whey protein concentrate and 50% wheat flour. The beta-carotene-rich cake made from orange-fleshed sweet potato flour (80%) + refined wheat flour (20%) is an excellent source of beta-carotene, i.e. 6.3 mg/100 g, and it fulfils the RDA of children and adolescents. The anthocyanin-rich cake made from purple-fleshed sweet potato flour (70%) + refined wheat flour (30%) is a good source of antioxidants containing about 39 mg/100 g anthocyanin.

19.13.6 Sweet Potato-Based Protein-Enriched Nutri Bars

The sweet potato-based protein-enriched nutri bar containing 20% sweet potato and 40% sweeteners (honey and jaggery), along with oats, puffed rice, Bengal gram, dhal and nuts, was found to be the best combination. Nutri bars fortified with sweet potato flour were developed using sweet potato flour (30%), Bengal gram (15%) and green gram (15%) with oats, nuts, etc.

19.13.7 Sweet Potato-Based Food Mixes

The ready-to-use paratha mix was prepared from sweet potato flour 50%, millet flour 15%, multigrain flour 30% and dried spices 5%. Ready-to-use sweet potato laddu mix made from purple-fleshed sweet potato flour (50%) + Bengal gram flour (50%) + sugar (20%) with addition of cardamom is a good source of anthocyanin. The ready-to-use weaning food mixes made from a composite of sweet potato flour (25%), arrowroot flour (10%), Chudda powder (20%), malted ragi flour (20%), rice flour (10%), sugar (6%), skim milk powder (8%) and starch (1%) are a good source of all the micronutrients.

19.13.8 Elephant-Food Yam-Based Products

Ready-to-fry nutri-shreds from elephant-foot yam were prepared, which can be used after frying with seasonings, curry leaves and coriander leaves. It is rich in omega-3 fatty acids and micronutrients and is a healthy snack for all age groups. Ready-to-fry papad was prepared from elephant-foot yam flour (30%) + black gram flour (40%) + green gram flour (30%). It has an expansion of 16.50% and contains protein (18.36 g) and fibre (3.51 g). Ready-to-cook healthy pasta was made from elephant-foot yam flour (35%), suji (45%) and finger millet (20%). It is a healthy breakfast for children, diabetics and obese persons and a good source of protein (14.63%), iron (3.45 mg/100 g) and calcium (336 mg/100 g).

19.13.9 Function Pasta/Spaghetti

Pasta as a food rich in complex carbohydrates with low glycaemic index is gaining wide acceptance in recent years. Pasta products, largely consumed all over the world, are traditionally manufactured from durum wheat semolina. ICAR-CTCRI developed an array of pasta products from tuber-based composite flours with high functional value coupled with low starch digestibility. Technology for making protein-rich pasta from cassava through fortification with protein sources like whey protein concentrate, defatted soy flour and fish powder was standardized at ICAR-CTCRI. They have excellent cooking quality and high protein content (10–15%). Sweet potato flour-based pasta rich in dietary fibre was made using dietary fibre sources like oat bran, wheat bran and rice bran. The slow digestibility of the fibre-enriched sweet potato pasta coupled with the high level of residual undigested starch makes these pastas ideal foods for diabetic and obese people. Hydrocolloid fortified pasta was prepared by incorporating guar gum, xanthan gum and locust bean gum at 1% level in cassava-maida blends. In vitro starch digestibility was slow and progressive over a period of 2 h for the control as well as the gum-fortified pastas, with a high retention of resistant starch after digestion. The effect of fortification of sweet potato flour with banana and legume starches as well as sweet potato starch itself in producing low glycaemic spaghetti (flour-based noodles) was investigated. Sweet potato:maida flour blend was fortified with commercial (edible) gum sources such as guar gum, xanthan gum and locust bean gum. The formulation contained 10% whey protein concentrate, which by virtue of its ability to mimic gluten helped to give excellent binding with starch and also elevated the crude protein content. Low glycaemic spaghetti was also developed successfully using the resistant starch source, NUTRIOSE. Gluten-free pasta from sweet potato flour-rice flour blends was developed along with additives such as whey protein concentrate and guar gum. Functional pasta was prepared from elephant-foot yam flour, suji and finger millet flour, and the resulted product had protein content 10.33–15.62%, fat content 1.92–2.30%, starch content 33–40% and sugar content 1.95–3.32%. The iron and calcium contents were 3.15–5.80 mg 100 g^{-1} and 320–390 mg 100 g^{-1}, respectively. The process for production of pasta from sweet potato-pseudo-millet-based composite flour was standardized with sweet potato flour (55%), millet flour (15%), maida (30%) and starch (5%) along with quinoa and buckwheat flour.

19.13.10 Rice Analogues

Rice analogue was prepared by the cold extrusion process from the composite flour containing cassava flour (45–60%), rice flour/maida (25–40%), guar gum (0–0.5 g), gelatinized starch (5%) and whey protein concentrate (10%). The rice analogue made from cassava-maida-whey protein concentrate-guar gum composite flour was more acceptable by sensory evaluation.

19.13.11 Extruded Products

Extrusion cooking is a high-temperature short-time cooking process designed for processing of starchy as well as proteinaceous materials. Being the treasure house of starches with complex physico-chemical properties, tuber flours/starches can be extruded to obtain a variety of nutritionally enriched, ready-to-eat/cook products. Tubers after washing, peeling and slicing into chips are dried and powdered in a hammer mill. The dry flour after conditioning to 12–15% moisture content is extruded by maintaining appropriate temperatures at different sections of the barrel and die of the food extruder. With the addition of low-cost protein sources like wheat, finger millet and soy flour, tubers, being rich in carbohydrates and lacking in protein content, gave more nutritional and market value products.

19.13.12 Cassava Starch, Sago and Wafers

The process of extraction of starch consists of peeling the tubers, rasping, screening, settling and drying. Peeled tubers of cassava are disintegrated into pulp by a rasper, which releases starch granules from the fibrous matrix. The resulting slurry is pumped onto a series of vibratory screens, the fibrous waste (thippi) is retained on them and the starch milk passing through the sieves is channelled into sedimentation tanks. After at least 8 h of settling, the supernatant liquor is decanted out and the starch cake settled at the bottom is scooped up for sun drying on a cement floor. Sago (Sabudana) is manufactured from the partially dehydrated (35–40% m.c.) starch cake. The lumps are broken in a spike mill and then globulated on a gyratory shaker. The globules are graded according to size and then partially gelatinized by roasting on shallow metal pans or by steaming. Finally, the sago pearls are dried in the sun on cement floor. The agglomerates are separated by means of a spike beater and polished before bagging. Wafers are made by arranging the wet granules in suitable dies and steaming. The steamed granules take the shape of the die, and after drying, it can be separated out from the dies and packed.

19.13.13 Functional Sago

Functional sago was prepared using beetroot powder and sweet potato leaf powder blended with reconstituted dry or wet cassava starch. The antioxidant activity and dietary fibre contents of the sago could be improved by the incorporation of beetroot powder. The total phenolic content (0.03 g g^{-1}) and antioxidant activity (IC_{50}) (39.13 mg) were maximum for the sago prepared from 94% reconstituted dry starch and 6% beetroot powder. The maximum resistant starch content of 19.46% was obtained for the sago prepared from 100% wet starch, whereas the total dietary fibre content was greater for the sago prepared from reconstituted dry and wet starches (94%) and beetroot powder (6%). The slowly digestible starch (SDS) and resistant starch (RS) contents were more in the sago prepared using beetroot powder. Based on the functional dietary fibre and resistant starch contents, sago made from reconstituted dry starch (94%) and sweet potato leaf powder (6%) was found to be the best. The dietary fibre content and in vitro antioxidant activity were comparatively higher in the functional sago made using sweet potato leaf powder.

19.14 Industrial Products

19.14.1 Starch-Based Adhesives

Liquid adhesives and gum pastes can be made from cassava starch using simple low-cost technologies. Starch is cooked with water and cooled, and preservatives like formaldehyde or copper sulphate are added. The shelf life of the gums can be improved by adding borax, urea, glycerol, carboxymethyl cellulose, etc. These chemicals help in improving and stabilizing the paste viscosity. The process for the preparation of a multipurpose binding paste based on cassava starch as a multipurpose adhesive and ready-to-mix two-part adhesive, which can be used for book binding, sticking labels on bottles, making envelops and paper pouches, etc., has been developed. Bench-scale technologies were also developed for corrugating adhesive with oxidized cassava starch as the carrier phase: single-phase corrugating adhesive with acid-thinned cassava starch, moisture-resistant corrugating adhesive based on native cassava starch and alkali-free corrugating adhesive dry mix based on cassava starch.

19.14.2 Starch Graft *Co*-polymers

Among the various modifications of starch, graft co-polymerization with vinyl monomers is a fascinating field for research with unlimited possibilities for improving starch properties. The process for the preparation of different graft co-polymers of cassava starch, viz. starch graft poly(acrylamide), starch graft poly(acrylonitrile) and starch graft poly(methacrylamide) co-polymers, has been standardized. The grafted starches of poly(acrylamide) and poly(methacrylamide) have cold swelling nature, high viscosity, water-absorption capacity and thermal stability. The graft co-polymers with acrylonitrile were water insoluble and did not undergo gelatinization even at 95 °C, and exhibited excellent thermal stability also. It can be used in oil drilling, sizing and printing of cotton fabrics, water treatment for the removal of heavy metal ions and as a flocculating agent.

19.14.3 Superabsorbent Polymers

Cassava starch can be modified as superabsorbent polymers through free radical graft co-polymerization with vinyl monomers and subsequent alkali saponification. A bench-scale process was developed for the production of a superabsorbent polymer by the alkali saponification of grafted cassava starch. It is semi-synthetic in nature, uses cassava starch backbone (one-third of the total weight) and contains no detectable level of the monomer. It has slow absorption and desorption of water, and equilibrium absorbency (<350–400 g/g of the dry sample) is reached in 2 h. It improves soil properties such as porosity, water-holding capacity and nutrient status. The polymer is effective in soil moisture retention and reduces watering interval of plants, especially in pots. Under controlled conditions such as in greenhouses for plant nurseries and ornamental and medicinal plants, it can be more effectively used. It is suitable in plant nurseries, garden plants, high-tech agriculture, etc.

19.14.4 Starch-Based Nanocomposites as Sustained Delivery Matrices for Therapeutic Drugs and Curcumin

Cassava starch/montmorillonite nanocomposites prepared using citric acid-activated MMT are found to be appropriate matrices for incorporating therapeutic drugs (theophylline) to attain sustained-release properties. Starch-konjac glucomannan blend films were developed for the sustained release of drugs. Water-soluble curcumin incorporated in octenyl succinate cassava starch nanoparticles was prepared by a wet grinding process. The nanocurcumin exhibited aqueous solubility and enhanced cellular uptake and anti-cancer potential. As revealed by pharmacokinetic studies in Wistar albino rats, the nanocurcumin formulation increased the curcumin bioavailability by 71.27%.

19.14.5 Resistant Starch

Resistant starch (RS) deserves special attention in the fast-developing food industry because of its inevitable role in combating metabolic diseases. The RS, the fraction of starch, which is not digested in the small intestine, while reaching large intestine fosters the growth of colon micro-biota and enhances butyrate production, which is essential for colon health. Cassava and sweet potato starches were subjected to different chemical and physical modification techniques to develop RS3-, RS4- and RS5-type resistant starches with fairly high content of slowly digestible starch (SDS) and medium glycaemic index. These resistant starches are beneficial in formulating low-calorie food and diabetic food, and it can act as a pre-biotic. These can be used to improve the nutritional value of various food products.

19.14.6 Natural Colourants

1. Anthocyanins from purple yam and sweet potato tubers/leaves
   Purified and concentrated anthocyanins from the tubers of purple yam (Acc. Da-340), purple-fleshed sweet potato (var. Bhu Krishna) and purple leaves of sweet potato (Acc. S-1467) were found to contain six and nine acylated anthocyanins, respectively. The nine sweet potato anthocyanins were cyanidin and peonidin derivatives, while all the six greater yam anthocyanins were cyanidin derivatives. The products have high antioxidant activity. These anthocyanins can be used as a natural colourant.
2. Encapsulated anthocyanin pigments
   Purified anthocyanins from purple yam and sweet potato tuber were encapsulated with maltodextrin by spray-drying technique. The product from purple yam has a total solid content of 97.41%, moisture 2.59% and yield after encapsulation 68.8%, whereas the total solid content is 98.5%, moisture 1.5% and yield after encapsulation 70.6% for the sweet potato tuber anthocyanins. They are stable at low temperatures and have high antioxidant activity and can be used as a natural colourant with added advantage of antioxidant activity. Capsules filled with coated/encapsulated anthocyanins were also developed as a nutritional supplement.

19.14.7 Biodegradable Films and Edible Coating

Starch forms an important ingredient for the development of biopolymer-based environment-friendly packaging materials to replace synthetic non-degradable materials mainly due to their renewability, abundance, low cost, film-forming properties, bland taste and colour, biodegradability, etc. However, starch has severe limitations because of its high solubility and poor water resistance, making starch products very sensitive to the relative humidity at which they are stored and used. The addition of modified starches in the preparation of bio-composites definitely improves the physico-mechanical and water resistance of the biodegradable packaging material. Studies have been carried out to develop biodegradable film from cassava starch modified by etherification, esterification, double cross-linking and enzymatic treatments by film casting method. Eco-friendly biodegradable composite films based on chitosan and konjac glucomannan were prepared for food wrapping application with incorporation of granular cassava starch to enhance the barrier properties and mechanical properties. Nanosilver has been incorporated in the films to achieve antimicrobial properties.

Cassava starch-konjac glucomannan blend was prepared and successfully used for edible surface coating of carrot slices to increase the shelf life. Water loss from the coated carrot slices was slower compared to that from uncoated samples. Coating significantly maintained the visual quality of carrot compared to uncoated samples throughout the storage period at low temperature. At room temperature, there was no significant change in the colour of coated samples until 21 days of storage, and thereafter a gradual change was observed. Coated samples showed less microbial growth on storage.

19.14.8 Cassava as a Biofuel Crop

Cassava with its high carbohydrate content and ability to grow under low management conditions, degraded soils and wide range of edaphoclimatic conditions has been globally recognized as a potential candidate for bioethanol production. Fresh cassava tubers, dry chips/flour or starch can be used for the production of ethanol. The process consists of three steps, viz. liquefaction, saccharification and fermentation. During liquefaction, the cooked starch slurry is hydrolysed to maltose and low-molecular-weight dextrins using either acids or α-amylase. In the saccharification step, hydrolysis to glucose is achieved using acids or glucoamylases. During fermentation, the glucose formed is fermented to ethyl alcohol using yeast, *Saccharomyces cerevisiae*. The process yielded up to 450 L of ethanol per tonne of starch. Nevertheless, the process was highly energy intensive due to the varying temperatures (100 °C, 60 °C and 30 °C) and pH (6.0 and 4.5) and time consuming (total of 122 h). Hence, the process technology was modified and essentially is a single-step conversion of cassava starch to ethanol, except for a 30-min thinning step requiring 90 °C. The entire saccharification-fermentation reaction could be performed at room temperature (30 ± 1 °C) in the presence of the new enzyme, Stargen, and yeast (*Saccharomyces cerevisiae*). The whole process duration was only 48 h and 30 min as compared to 5 days in the earlier process (liquefaction 2 h, saccharification 48 h and fermentation 72 h). The ethanol yield (from laboratory-level batch process) was approximately 680 L/tonne of starch.

19.14.9 Modified Cassava Starch

The processes for the preparation of an array of physically and chemically modified starches of cassava have been standardized. Chemically modified starches include cross-linked starch, starch succinate, octenyl succinate starch, starch citrate, hydroxypropylated starch, oxidized starch and starch phosphate. The physical modifications include heat-moisture treatment, annealing and pre-gelatinization. The modified starches have got wide application in the food, pharmaceutical and other industries as food ingredient in salad dressings, frozen foods, canned foods and puddings; thickener and viscosity modifier in soups, jellies and fruit pastes; surgical dusting powders; carriers; absorbents and ion-exchange resins; paper and adhesive industry material; tablet disintegrant; instant binder, etc.

19.15 Cassava Stem-Based Particle Boards

Cassava is extensively cultivated as a sole crop or intercrop in many states of our country. Its propagation is through stem cuttings. The total planting material required for planting cassava in one hectare worked out to be 10,000 cuttings, and its planting material multiplication is about 10–15 times. Hence, in the subsequent year, planting requires only 15–20% of the total stem produced, and hence 80–85% of the material is available for other uses. At present, in major cassava-growing areas, the stems are cut into small pieces and incorporated into the soil during tillage operations or used as firewood in small scale. Despite being a good source of cellulosic and fibrous residue, the stems are still underexploited mainly due to the lack of proper technologies for converting them into value-added products. Hence, considering the wide-scale cultivation and processing of cassava, the utilization of its stem along with starch factory waste for making briquettes/particle board gives ample scope for its effective value addition. Particle boards have been developed from cassava stem using synthetic resins urea formaldehyde, phenol formaldehyde and melamine formaldehyde, and the properties of the boards obtained are in conformity with those of BIS values. Also, studies had been carried out to use native and modified cassava starch as bio-adhesive to prepare green particle board from cassava stem.

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Legume Vegetables for Human Nutrition and Entrepreneurship

20

T. S. Aghora, M. Thangam, and Naganagouda Patil

Abstract

Protein-energy malnutrition (PEM) is a major nutritional syndrome affecting over 170 million preschool children and lactating women in developing countries. Legumes are the cheapest source of significant amount of protein, minerals, and vitamins, which are essential for normal human growth and development. Hence, protein-rich legume vegetables have a major role to play in eradicating such malnutrition problems. So, consumption of legume vegetable needs to be given attention. Nutritive and therapeutic value and anti-nutritional factors of garden pea, French bean, vegetable cowpea, Dolichos bean, winged bean, cluster bean, vegetable soybean, and broad bean are discussed in this chapter. Further, the role of legume vegetables in starting entrepreneurship through seed production is also highlighted.

Keywords

Legume vegetables · Nutritive value · Therapeutic value · Anti-nutritional factors · Seed production

20.1 Introduction

Legumes are dicotyledonous annuals or perennials belonging to Fabaceae family and are cultivated around the world for their nutritious pods and seeds. Legumes are a staple food for many cultures all over the world (Kousris-Blazos and Belski 2016). In addition to their nutritional superiority, legumes have also been ascribed

T. S. Aghora (✉) · M. Thangam · N. Patil
ICAR-Indian Institute of Horticultural Research, Bengaluru, Karnataka, India

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economical, cultural, physiological, and medicinal roles owing to their possession of beneficial bioactive compounds (Philips 1993). Legumes are not only a cheap source of nutrients but also a major source of income. Consumption of legumes dates back to as early as 5500 BC, and they are thought to be one of the first crops cultivated by man (Sandlin 2010). Legumes are well adapted to adverse environmental conditions and highly resistant to diseases and pests (Bravo et al. 1999).

The high cost and limited supply of animal proteins have necessitated contemporary research efforts towards utilization of locally available food crops, especially underutilized legumes (Khattab et al. 2009). In developing countries like India, where the larger population comes under low-income category, attention must be given to cheap, easily available, and accessible nutritious plant protein sources like legumes. Major legume vegetables grown in India are French beans, garden peas, cluster beans, cowpea/yard-long bean, Dolichos bean, winged bean, faba beans, and vegetable soybean.

Protein-energy malnutrition (PEM) is a major nutritional syndrome affecting over 170 million preschool children and lactating women in developing African and Asian countries (Staniak et al. 2014). PEM is an imbalance between the supply of protein and energy and the body's demand for them to ensure optimal growth and function. Hence, protein-rich legume vegetables have a major role to play in eradicating such malnutrition problem. So, consumption of legume vegetable needs to be given attention.

Apart from meeting nutritional requirement of humans, legume vegetables are also a source of income. One can take up seed production in legumes easily, which are highly self-pollinated crops and are free from the hassling emasculation and crossing methods for seed production. Also, it is not necessary to maintain wider isolation distance to avoid physical mixtures, which is a prerequisite for seed production for most of the vegetable crops. Seed extraction is also not a difficult process as compared to solanaceous vegetables like tomato.

Entrepreneurial opportunities other than commercial seed production include guar gum extraction and export in cluster bean and garden pea processing (like canning, freezing and dehydration) for off-season market and export to other countries. The Indian Institute of Horticultural Research, Bengaluru, has released many varieties in vegetable legumes like French beans, garden pea, cowpea, and Dolichos bean for different states, which can be utilized for seed production by farmers for doubling the farm income and to become entrepreneurs in commercial legume vegetable seed production.

20.2 Importance of Legume Vegetables

- Legume vegetables are grown for their tender green pods/green seeds either for fresh consumption or for processing as canned, frozen, or freeze-dried product. Legumes are the cheapest source of significant amounts of protein, minerals, and vitamins, which are essential for normal human growth and development.

- They improve soil fertility by fixing atmospheric nitrogen (30–85 kg/ha; some legumes like cowpea and Dolichos: >100 kg/ha). Legumes also improve soil quality by increasing soil organic matter, improving soil porosity, improving soil structure, decreasing soil pH, diversifying the microscopic lifestyles in the soil, and braking disease buildup and weed problems of grass-type crops (Muthuraman et al. 2020). Legumes play a necessary function in soil microbial biomass and energetic key strategies such as nutrient cycling and soil organic matter decomposition and thus improve crop productiveness and soil sustainability (Graham and Vance 2000).
- Suitable for any of the cropping systems (short duration and stature): Legumes play an important role in cropping systems to decrease or eliminate the need for direct applications of some fertilizers. When maize is intercropped with leguminous cover crops, the leguminous crops contribute significantly to N nutrition of the maize crop (Sinha et al. 1994). Yadav et al. (2003) reported that yields of wheat following cowpea were significantly greater by 19–20%, compared with those following rice. Similarly, yields of wheat following soybean were significantly greater by 25% compared with those following sorghum (Ghosh et al. 2004).
- Legume vegetables are nutritionally rich: Legumes are considered as foods with low glycemic index values, which have been shown to play a role in glycemic control in patients with type 2 diabetes mellitus (Brand-Miller et al. 2003). Soluble fiber and folate present in legume vegetables can prevent type 2 diabetes, certain cancers, and cardiovascular diseases (Linus Pauling Institute of Oregon State University).

Area and production of legume vegetables (Source: NHB statistics, 2018)

Crop	Area (l ha)	Production (l t)	Productivity (t/ha)
French bean	2.30	22.80	9.90
Veg. cowpea	0.60	4.90	8.16
Garden pea	5.40	54.20	10.03
Dolichos bean	0.90	8.10	9.00
Other legume vegetables	0.50	5.00	10.00
Total	9.70	95.00	9.41

20.2.1 French Bean: *Phaseolus vulgaris* L. $2n = 2x = 22$

French bean (*Phaseolus vulgaris* L.) belongs to the Fabaceae family and originated in Southern Mexico and Central America. It is commonly known as dry bean, pinto bean, field bean, navy bean, and kidney bean and is one of the most popular and widely grown vegetables in India. Its tender pods and matured seeds are consumed as vegetable. This vegetable not only plays a vital role in human nourishment but also improves soil fertility by atmospheric nitrogen fixation. Major growing states in India are Punjab, Maharashtra, Jammu and Kashmir, Gujarat, Karnataka, Tamil

Nadu, and Uttar Pradesh. In India, the area under French bean is 2.3 lakh ha with a production 22.8 lakh tonnes and productivity 9.9 tonnes/ha (NHB database, 2018). It is a short-duration crop (45–70 days) mainly grown in *kharif*. If irrigation facilities are available, it can be grown in *rabi* and summer.

It is an excellent vegetable crop for pods as well as for seed and is of worldwide significance for direct human consumption and a dietary supplement rich in proteins, vitamins, and minerals such as calcium, phosphorus, iron, and zinc (Broughton et al. 2003). French bean is quite nutritious and a potential source of protein, carbohydrates, and minerals. The mineral matter, crude fiber, and ether extract are concentrated in seed, while crude protein and energy are stored in cotyledons (Singh and Yadav 1997). French beans have the highest antioxidant capacity because of significantly higher levels of total phenolic, ascorbic acid, and β-carotene (Amin et al. 2009).

Nutritional components of French bean (Gopalan et al. 1999)

Constituents	Quantity (per 100 g)	Constituents	Quantity (per 100 g)
Moisture	91.4	Potassium	129 mg
Carbohydrates	4.50 g	Sulphur	37 mg
Proteins	1.70–2.50 g	Vitamin A	221 IU
Fats	0.10 g	Thiamine	0.08 mg
Energy	31 kcal	Riboflavin	0.06 mg
Dietary fiber	2.70 g	Nicotinic acid	0.30 mg
Iron	1.70 mg	Vitamin C	16.00 mg
Phosphorus	28.0 mg	Folic acid	734 mcg
Calcium	50 mg	Vitamin B_6	738 mcg

Health benefits of French beans (Narayana 2020)

- Antioxidants: Resistance against infectious diseases and scavenge the reactive oxygen to nullify the free radicals: carotenoid: lutein, beta-carotene, violaxanthin, and nea-xanthin.
- Flavonoids: Quercetin, kaempferol, catechin, epicatechin, and procyanidins.
- Dietary fiber (2.7 g): Acts as a laxative that helps to protect the mucus membrane of the colon by decreasing its exposure to toxins.
- Reduces blood cholesterol levels by decreasing reabsorption of cholesterol-binding acids in the colon.
- The soluble fiber slows down the metabolism of carbohydrates, which, in turn, regulates the blood sugar levels and prevents a sudden jump in blood sugar levels after meals. It is good for diabetic people and those with insulin resistance.
- Zeaxanthin: Helps in preventing the age-related eye diseases.
- Folate (734 mcg): This helps in preventing neural tube defects in the growing fetus and prevents the accumulation of an intermediary metabolite of protein metabolism, called homocysteine, which promotes the risk of atherosclerosis.
- Copper: Lowers the risk of rheumatoid arthritis and maintains the elasticity of blood vessels, joints, and ligaments by enhancing the activity of the enzymes.

- Magnesium: Helps in relieving fatigue and relaxing sore muscles, nerves, and blood vessels, thereby relieving the symptoms of asthma and migraine headaches.

Therapeutic properties of French bean

- Antidiabetic: α-Amylase inhibitor present in French bean slows the absorption of carbohydrates through the inhibition of enzymes responsible for their digestion.
- Anti-hyperlipidemia: Baked or cooked beans have cholesterol-lowering effect.
- Anti-cancerous: Dimeric 64 kDa glucosamine-specific lectin purified from the seeds of French beans exhibited antiproliferative activity towards breast cancer (MCF7) cells, hepatoma (HepG2) cells, and nasopharyngeal carcinoma (CNE1 and CNE2) cells (Chan et al. 2012).

20.2.2 Garden Pea: *Pisum sativum* L. $2n = 2x = 14$

Garden pea (*Pisum sativum* L.) belongs to the family Fabaceae and originated in Central Asia. It is also called as sweet pea and is a choice vegetable grown for its fresh shelled green seeds rich in protein (7.2%), vitamins, and minerals. Garden pea is a cool-season crop mainly grown during winter season in plains and during summer season in hills. Major area of garden pea is in temperate and subtropical regions of the country. Important states in India include Uttar Pradesh, Bihar, Haryana, Punjab, Himachal Pradesh, Orissa, and Karnataka. It is also grown in cooler parts of southern India. In India, the area under garden pea is 5.4 lakh ha with a production of 54.2 lakh tonnes and productivity is 10.03 tonnes/ha (NHB database, 2018).

Peas have long been recognized as inexpensive, readily available sources of protein, complex carbohydrates, vitamins, and minerals. The high nutrient density of peas makes them a valuable food commodity, capable of meeting the dietary needs of the estimated 800–900 million undernourished individuals worldwide (FAO stats 2011). Pea is highly nutritive, containing a high percentage of digestible proteins, carbohydrates, and fats along with minerals (Ca, P, and Mg) and vitamins A, B, and C. It contains a good amount of soluble and insoluble fiber and contains no cholesterol. In addition to folates, peas are also good in many other essential B-complex vitamins such as pantothenic acid, niacin, thiamine, and pyridoxine. Peas are a rich source of critical cardioprotective B vitamin, choline (40.9 mg), and polyphenol called coumestrol (2 mg), which decreases the risk of stomach cancer.

Nutritional components of pea

Constituents	Quantity (per 100 g)	Constituents	Quantity (per 100 g)
Moisture	72.0 g	Calcium	20 mg
Carbohydrates	15.8 g	Potassium	79 mg
Proteins	7.2 g	Magnesium	34 mg
Fats	0.1 g	Vitamin A	139 IU
Energy	93 kcal	Thiamine	0.25 mg

(continued)

Constituents	Quantity (per 100 g)	Constituents	Quantity (per 100 g)
Dietary fiber	4.0 g	Riboflavin	0.01 mg
Iron	1.5 mg	Niacin	0.80 mg
Phosphorus	139 mg	Vitamin C	9 mg

Phytochemicals in garden pea (Narayana 2020)

- Flavonoids: Catechin and epicatechin—to prevent the inflammatory bowel disease
- Carotenoids: Alpha-carotene and beta-carotene—alpha: lowers the risk of cardovascular diseases; beta: prevents eye diseases
- Phenolic acids: Ferulic acid and caffeic acid—skin integrity; prevents cancer, premature aging; reduces exercise-related fatigue
- Polyphenols: Coumestrol—reduces bone loss and promotes mineralization of bones
- Anti-inflammatory phytonutrients: *Pisum* saponins I and II, pisumosides A and B—anticarcinogen, antidiabetic, hepatoprotective property
- Omega-3 fatty acid: Alpha-linolenic acid—prevention of heart and blood vessel diseases

Health benefits of garden pea (Narayana 2020)

- Folic acid (274 mcg): Folates are B-complex vitamins, which help to prevent neural tube defects in newborn babies.
- Vitamin B, choline (40.9 mg): Critical cardioprotective.
- Ascorbic acid (40 mg): Helps to develop resistance against infectious diseases and scavenge harmful, pro-inflammatory free radicals.
- Phytosterols especially β-sitosterol: Lowers cholesterol levels.
- Vitamin K (24.8 mcg) (phylloquinone): Pea leaves are rich in phylloquinones and found to have a potential role in bone mass-building function by promoting osteotrophic activity in the bone. Helps to prevent Alzheimer's disease by limiting neuronal damage in the brain.
- Flavonoids such as carotenes, lutein, and zeaxanthin as well as vitamin A (765 IU or 25.5% of RDA/100 g): Consumption of natural fruits rich in flavonoids helps to protect from lung and oral cavity cancers. Vitamin A is an essential nutrient, which is required for maintaining healthy mucus membranes and skin and also essential for vision.
- Anthocyanins isolated from purple pods of pea: Show moderate stability and antioxidative activity.

20.2.3 Dolichos Bean: *Lablab purpureus* L. $2n = 2x = 20$

Dolichos bean (*Lablab purpureus* L.) belongs to the family Fabaceae and originated in India. It is also commonly known as lablab bean, hyacinth bean, Indian bean, Egyptian bean, and sem. It is grown for vegetable, pulse, fodder, green manure, cover crop, medicine, and ornamental purpose (Ayyangar and Nambiar 1935). The major growing states in India are Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, Uttar Pradesh, and Northeast India. In India, the area under Dolichos bean is 0.90 lakh ha with a production of 8.1 lakh tonnes and productivity is 9 tonnes/ha (NHB database, 2018). It is mostly grown as a winter-season vegetable crop. The bush type of Dolichos, being photo-insensitive, can be grown in all seasons. Apart from being drought tolerant, it has high adaptability to a wide range of production conditions.

Dolichos is a multi-utility and multi-beneficial leguminous crop. The crop is rich in protein (3.6%) and fiber (1.8%). The dry seed contains 23.0–28.0% protein. The pods are also rich in phenol (1.7–9.67 mg/100 g), which is a potential antioxidant (Rai et al. 2014). It is also a very good source of amino acids (lysine), vitamin (A, C and riboflavin), and minerals (Ca, Fe, Mg, S, Na, and P) (Deka and Sarker 1990). The seeds contain kievitone, which is one of the potential breast cancer-fighting flavonoids (Hoffman 1995). Tyrosinase present in the seed has greater potential for the treatment of hypertension in human beings (Naeem et al. 2009). The beans are used as stomachic, anthelmintic, diuretic, aphrodisiac, antispasmodic, digestive, febrifuge, carminative, and laxative (Kirtikar and Basu 1995). It is also rich in bioactive compounds that are very advantageous to cure particular diseases such as liver problems (Kim et al. 2017), diabetes (Wardani et al. 2015), and tumor (Vigneshwaran et al. 2017).

Nutritional components of Dolichos bean

Constituents	Quantity (/100 g)	Constituents	Quantity (/100 g)
Energy	209 kJ	Folate	47 μg
Carbohydrates	9.2 g	Vitamin C	5.1 mg
Fat	0.27 g	Calcium	41 mg
Protein	2.95 g	Magnesium	42 mg
Vitamin B1	0.056 mg	Potassium	262 mg
Vitamin B2	0.088 mg	Zinc	0.38 mg
Vitamin B3	0.48 mg	Iron	0.76 mg

Health benefits of Dolichos beans

- Copper: Essential for the brain pathways such as galactose and dopamine, which helps to maintain mood and focus. Also associated in utilizing tyrosinase, ascorbate oxidase, superoxide dismutase, and vitamin C.
- Vitamin B1 (0.056 mg/100 g): Vital for the production of acetylcholine, which is a neurotransmitter that relays messages from the nerves to the muscles. Heart depends on these signals, which helps counteract heart disease as it maintains the healthy ventricular function and treats heart failure.
- Zinc (0.38 mg): Has antioxidant and anti-inflammatory properties, which help to counteract oxidative stress and reduce the risk of diseases. Zinc assists the healthy cell division, prevents mutation of cells, and prohibits tumor growth.
- Manganese: Reduces the oxidative stress as well as inflammation by producing the SODs, which helps to heal the lungs.

- Fiber: Insoluble fiber helps to prevent bloating, constipation, and indigestion. Soluble fiber helps in digestion by absorbing water to form a viscous substance, which is fermented by the bacteria in a digestive tract.
- Magnesium (42 mg): Reduces the symptoms of insomnia and improves sleep time and sleep efficiency. It also reduces cortisol.
- Vitamin D: Reduces gum inflammation that is related with periodontal gum disease.
- Potassium (262 mg/100 g): Reduces muscle cramps and improves the strength of muscles.

Traditional uses of Dolichos bean in various countries

- Peninsular Malaysia: Leaves are used with rice flour and turmeric as a poultice for eczema. An infusion made from leaves is used to treat gonorrhea.
- Indo-China: Leaves are used for colic pain.
- East Africa: Crushed leaves are used to cure headache. Green leaves with vinegar are used to cure snakebites.
- Rwanda: Decoction made from leaves is used to cure heart problems.
- Democratic Republic of Congo: An infusion made from leaves is used to treat sore throat and tonsillitis.
- Asia: Flowers are used as antivirus, alexiteric, and carminative.
- Assam: Pod juice is used to treat inflammation of ear and throat.
- China: Uses the boiled ripe seeds as a carminative and tonic.
- India: Seeds are used to stop nose bleeding.
- Senegal: Seed is used as stomachic and antispasmodic and as a treatment for sunstroke and cholera.

Therapeutic properties of Dolichos bean

- Antidiabetic effect: Methanol extracts of Dolichos pods have antihyperglycemic properties by way of reducing blood glucose levels.
- Anti-anemia effect: Increases hemoglobin level and hematocrit level.
- Hypolipidemic effect: Reduces plasma cholesterol.
- Antilithiatic activity: Prevents the formation of kidney stones or relieves the symptoms of kidney stones.

20.2.4 Vegetable Cowpea and Yard-Long Bean

Vigna unguiculata ssp. unguiculata and sesquipedalis $2n = 2x = 22$

Cowpea (*Vigna unguiculata*) belongs to the Fabaceae family and originated from West and Central Africa (Faris 1965). It is an annual legume and is also commonly referred to as southern pea, black-eyed pea, crowder pea, lubia, niebe, or frijole. Cowpea is a herbaceous legume adapted well to warm climate with adequate rainfall and is widely cultivated in Africa, Southeast Asia, and South and North America. Its long green tender pods are used as vegetable, and seeds are used as pulse and also provide cheap livestock feed. Cowpea also helps in checking the soil erosion as it produces a heavy vegetative growth and covers the ground well (Pal et al. 2004). The major growing states in India are Punjab, Haryana, Delhi, Uttar Pradesh, Rajasthan, Karnataka, Kerala, Tamil Nadu, Maharashtra, and Gujarat. In India, the area under vegetable cowpea is 0.60 lakh ha with a production of 4.90 lakh tonnes and productivity is 8.16 tonnes/ha (NHB database, 2018).

It is a short-duration, drought-resistant crop. Pods and seeds are highly nutritious (rich in protein, calcium, phosphorus, iron, carotene, thiamine, and riboflavin). Cowpea is considered as nutrient-rich food with low energy density. Cowpea has been promoted as a high-quality protein component of the diet among economically depressed communities in developing countries, with an aim of reducing the high prevalence of protein and energy malnutrition (Animassaun et al. 2015). Epidemiological evidence indicates that the consumption exerts protective effective against the development of several chronic diseases, such as gastrointestinal disorders (Trehan et al. 2015), hypercholesterolemia, obesity (Frota et al. 2008), diabetes (Rotimi et al. 2013), and several types of cancer (Khalid and Elharadallou 2013). Unguilin—a protein isolated from cowpea—inhibits human immunodeficiency virus-1 (Ye and Ng 2001). Unguilin also has antifungal property.

Nutritional components of vegetable cowpea

Constituents	Quantity (per 100 g)	Constituents	Quantity (per 100 g)
Moisture	85.3 g	Potassium	242 mg
Carbohydrates	8.10 g	Calcium	72 mg
Proteins	3.50–4.5 g	Magnesium	60 mg
Fats	0.20 g	Carotene	564 μg
Energy	48 kcal	Thiamine	0.07 mg
Dietary fiber	2.0 g	Riboflavin	0.09 mg
Iron	2.5 mg	Niacin	0.9 mg
Phosphorus	59 mg	Vitamin C	14 mg
		Folates	64 mcg

Health benefits of vegetable cowpea (Narayana 2020)

- Rich in protein (23–32%) and fiber: Helps in weight management, cholesterol reduction, diabetes, cancer, etc.
- Low glycemic index: Helps in regulating blood sugar levels in diabetics.
- Lysine and tryptophan: Essential for immunity development and mood elevation.
- Minerals like K, Mg, Ca, P, and Fe: Role in body fluid maintenance, cardiac function, osteoporosis, and blood formation.
- Protein inhibitors (Bowman-Birk protease inhibitors): Responsible for antiproliferative activity and therefore control certain types of cancer.
- Antioxidants—Mainly carotenoids: light brown, red, and black cowpea varieties are rich in antioxidants.

20.2.5 Winged Bean: *Psophocarpus tetragonolobus* L. $2n = 2x = 18$

Winged bean (*Psophocarpus tetragonolobus* L.) belongs to Fabaceae family and the place of origin is uncertain, but Madagascar is considered as the probable center of origin. It is also known as asparagus pea, Manila bean, Goa bean, ridged bean, and four-angled bean. Its parts such as green pods, tubers, flowers, and leaves are consumed. It is considered an orphan crop though it is known for its high yield potential and nutritional value when compared to soybean (Vatanparast et al. 2016). The winged bean has been cultivated for generations in humid tropics of South and Southeast Asia, especially India, Bangladesh, Sri Lanka, Burma, Malaysia, Indonesia, and Papua New Guinea. In India, it is grown in Assam, Manipur, Mizoram, Kerala, Karnataka, and Tamil Nadu by the tribal people as a backyard crop.

Winged bean is popularly known as "One Species Supermarket" for its nutrient-dense green pods, immature seeds, tubers, leaves, and mature seeds. Winged bean seeds contain high dietary protein due to their amino acid content, substantial protein bioavailability, and low levels of anti-nutritional factors (Wan et al. 2014). Immature pods of winged bean contain 1–3% proteins and several vitamins and minerals (Tanzil et al. 2019). The mature seeds of winged bean contain 28–45% proteins and raw tubers contain 12–19% protein and 1–4% fat (Adegboyega et al. 2019). The leaves of winged bean contain several vitamins and minerals, especially vitamin A (National Research Council 1981).

Nutrient composition of winged bean

Constituents	Quantity (per 100 g)	Constituents	Quantity (per 100 g)
Energy	1711 kJ	Vit. B_3	3.09 mg
Carbohydrates	41.7 g	Vit. B_6	0.0175 mg
Dietary fiber	25.9 g	Calcium	440 mg
Fat	16.3 g	Iron	13.44 mg
Protein	29.65 g	Potassium	977 mg
Thiamine	1.9 mg	Manganese	3.721 mg
Magnesium	326 mg	Copper	5.2 mg

Health benefits of winged beans

- Tryptophan: Alleviates pain related with tension headaches and migraines and helps to cure nausea and sleep problems experienced by many migraine victims.
- Copper (5.2 mg): Strong antioxidant that works in the presence of the antioxidant enzyme superoxide dismutase to safeguard the cell membranes from free radicals.
- Manganese: Cures sprains and inflammation by increasing the superoxide dismutase level.
- Thiamine (1.9 mg): Helps to defend against vision problems like cataracts and glaucoma. This is due to its ability to influence nerve and muscle signaling, which is important in relaying information from the eyes to the brain.
- Fiber: Aids in digestion and preventing constipation.

- Phosphorus: Removes minor health problems like muscle weakness, numbness, and fatigue.
- Calcium (801 mg): Has direct effect on the pancreatic cells that control insulin secretion and therefore blood sugar levels.
- Magnesium (326 mg): Cures chronic asthma by normalizing breathing by relaxing the bronchial muscles and regulating breathing.
- Zinc: Helps in fighting colds and symptoms of illnesses.

Traditional uses of winged bean

- In Malaya, roots are used as a poultice (soft moist mass) to treat vertigo and leaves are used in the treatment of smallpox (Massurt 1895).
- In New Guinea, pods and edible tubers are considered roborant (tonic) (Stopp 1962).
- Pod extract is used to treat boils and ulcers (Perry and Metzger 1980).
- Bean seed extracts show radical scavenging, antimicrobial, and antioxidant activities (Nazri et al. 2011; Yoga Latha et al. 2007).

20.2.6 Vegetable Soybean (Edamame): *Glycine max* (L.) Merr. $2n = 2x = 14$

Vegetable soybean (*Glycine max* (L.) Merr.) belongs to the Fabaceae family and probably originated in North-Eastern China, a region where wild soybeans exist. It is similar to soybean, but it is harvested at full-seed development stage with larger, sweet nutty, and mild-flavor seed (Zhang et al. 2015). Vegetable soybean is known for its nutritional and medicinal values, and it was consumed as vegetable in the Far East as early as the second century BCE (Shanmugasundaram 2001; Shutleff and Aoyagi 2009). Vegetable soybean consumption is increasing rapidly, especially in Japan, Korea, China, and Taiwan. In India, grain soybean is commonly grown all over the country for oil and meal, and vegetable soybean is new for both farmers and consumers. Improved vegetable soybean varieties developed at AVRDC have been introduced and distributed in Northeast India. It has a short duration of crop cycle that allows it to fit in any crop rotation system and requires very low input to grow and is also a soil-enriching crop.

Green vegetable soybean seed has up to 13% protein on a fresh weight basis and high level of monounsaturated fatty acids and vitamins C and E; it is also one of the few natural sources of anticancer isoflavones. Cooked vegetable soybean has the highest net protein utilization value (NPU; the ratio of amino acid converted to protein). Frozen edamame can be used as a weight-loss ingredient to lessen the intake of food. The lower trypsin inhibitor levels and lower cell density make it more digestible than grain-type soybeans; it has only a shorter cooking time, and cooking edamame has the benefit of doubling the iron availability (Chadha and Oluoch 2004).

Vegetable soybeans differ from regular soybeans

- Vegetable soybean has double the protein (22%) and six times the energy content of green peas, with 60% more calcium and twice the phosphorus and potassium levels.
- They are usually large seeded with mild taste, tender, and easily digestible.
- Harvesting vegetable soybeans at the right time is critical for maximum texture and flavor because loss of quality occurs when pods turn yellow.
- The quality is best when the pod is plump and bright green, similar to snow peas (*Pisum sativum*), in color.

Comparison between vegetable soybean and mature soybean

Component	Vegetable soybean (RDI)	Mature soybeans (RDI)
Folate	78%	14%
Vitamin K1	33%	24%
Thiamine	13%	10%
Riboflavin	9%	17%
Iron	13%	29%
Copper	17%	20%
Manganese	51%	41%

Health benefits of vegetable soybean

- β-Conglycinin: Increases specific protein levels in the blood, which can in turn result in improved metabolism.
- Omega-3 fatty acids: Known to help with heart diseases and can reduce the risk of stroke. The fiber in soybeans can also reduce the cholesterol levels in the body by scraping excess cholesterol off the walls of blood vessels and arteries.
- Isoflavones: Are essential components of the female reproductive system. Isoflavones in soybeans can help protect against spinal bone loss.
- Oligosaccharides: Known to help stimulate the production of healthy bacteria in the intestines, thus serving as a great source of prebiotics.
- Hypotensive properties: Help in reducing blood pressure.
- Insulin receptors: Help in the prevention and management of diabetes, primarily because they have shown an ability to increase insulin receptors in the body.
- Magnesium: Helps in reducing sleep disorders and the occurrence of insomnia.

20.2.7 Cluster Bean: *Cyamopsis tetragonoloba* $2n = 2x = 14$

Cluster bean (*Cyamopsis tetragonoloba*) belongs to the family Fabaceae and originated in India. It is known as guar in India. Cluster bean is an annual legume plant widely grown for its gum, vegetable, and fodder. It is used as a vegetable at tender stage, in southern parts of India. It has appreciable amount of nutritional values and is rich in proteins, fat, carbohydrate, vitamin A, vitamin C, calcium, and iron. India is the largest producer, accounting for 80% of world's total production. Important states growing cluster bean are Rajasthan, Gujarat, Haryana, and Uttar

Pradesh. The seed of cluster bean contains about 30–33% gum in the endosperm. The discovery of the galactomannan (Mol. Wt.—50,000–8,000,000) gum in the endosperm made it an industrial crop. Cluster bean is well adapted to arid and semiarid regions because of its low water requirement.

It is a rich source of protein, fats, carotenes, P, Ca, and mineral salts needed in foods for human beings and feed and fodder for animals, which contains 42% crude protein, and seeds contain 29–31.4% gum (Kumar and Rodge 2012). Guar gum is also considered as a potential drug treatment of disease like high cholesterol (Hosobuchi et al. 1999), diabetes (Saeed et al. 2012), and irritable bowel syndrome (Russo et al. 2015). Guar seeds and leaves were reported to be used in the treatment of various diseases in India and Pakistan (Saleem et al. 2002).

Nutrient composition of cluster bean

Constituents	Quantity (per 100 g)	Constituents	Quantity (per 100 g)
Carbohydrates	10 g	Phosphorus	250 mg
Dietary fiber	2.5 g	Vit. A	330 IU
Fat	0.2 g	Ash	1.5 g
Protein	4 g	Thiamine	0.09 g
Vit. C	50 mg	Riboflavin	0.06 g
Calcium	100 mg	Niacin	0.6 g
Iron	6 mg	Vit. B_6	0.088 mg

Health benefits of cluster beans

- Iron: Soluble and absorbable form reduces the chances of anemia. Enhances hemoglobin content within RBCs and enhances oxygen consumption capacity of the blood, therefore enhancing better blood circulation.
- Glyconutrients: Control blood sugar levels. Cluster beans are low in glycemic index and therefore do not cause rapid fluctuations in the blood sugar levels.
- Phosphorus and calcium: Fortifies bones and enhances bone health.
- Folic acid: Vital for pregnant women.
- Hypoglycemic and hypolipidemic compounds: Natural aid for people suffering from hypertension. As diabetes and heart disease increase the risk of hypertension, the combined effect of these compounds plays an important role in controlling your blood pressure levels.
- Vitamin K: Helps to induce normal development of fetus and reduce any birth complication.

20.2.8 Broad Bean: *Vicia faba* L. $2n = 2x = 12$

Broad bean (*Vicia faba* L.) belongs to the family Fabaceae, and the near east is considered as the center of origin for faba bean (Cubero 1974), while China seems to be a secondary center of faba bean genetic diversity (Zong et al. 2010). It is also known as faba beans, horse beans, and field beans and is among the oldest crops in the world. It is used as a high-protein food, which is popular in Uttarakhand, UP, HP, and Tamil Nadu. The fresh and dry seeds of broad bean are used for human consumption; they are highly nutritious because they have a high protein content (up to 35% in dry seeds) and are a good source of many nutrients, such as K, Ca, Mg, Fe, and Zn (Lizarazo et al. 2015; Neme et al. 2015). The crop is well adapted to various climates and is grown for both human and animal nutrition (Duc et al. 2015). In India, it is cultivated in northern states during rabi in plains and during kharif in hilly region.

It has industrial value as it is rich in levo-dihydroxyphenylalanine (L-DOPA), the precursor of dopamine. Its consumption can increase the L-DOPA levels in the blood, with a marked improvement in the motor performance of patients suffering from Parkinson's disease (Liu et al. 2000; Apaydin 2000). Faba bean is also being investigated as a dietary complement for other diseases such as hypertension, renal failure, and liver cirrhosis (Kwok et al. 1997; Randhir and Shetty 2004).

Nutritional components of broad bean

Constituents	Quantity (per 100 g)	Constituents	Quantity (per 100 g)
Energy	1425 kJ	Folate	423 mcg
Carbohydrates	58.29 g	Vit. C	1.4 mg
Fat	1.53 g	Calcium	103 mg
Protein	26.12 g	Magnesium	192 mg
Vit. B_1	0.555 mg	Potassium	1062 mg
Vit. B_2	0.333 mg	Zinc	3.14 mg
Vit. B_3	2.832 mg	Iron	6.7 mg

Health benefits of broad bean

- L-DOPA and carbidopa: Reduce the symptoms of Parkinson's disease: leads to the death of brain cells responsible for the production of the neurotransmitter dopamine; this causes some symptoms, such as tremor, decreased mobility, and stiffness of movement.
- Glutathione: Strengthens the immune system: contains compounds that enhance antioxidant activity, such as glutathione, and delay cell aging, as they combat free radicals that cause cell damage and disease.
- Iron: Reduces the symptoms of anemia: symptoms of anemia include shortness of breath, dizziness, and fatigue, as well as a feeling of general weakness. Note: People with a rare genetic condition known as glucose-6-phosphate dehydrogenase (G6PD) should avoid raw broad beans, for whom ingestion may cause "favism" which is a type of anemia.
- Fiber: Helps to lose weight: a diet rich in fiber and protein promotes a feeling of fullness and reduces calorie consumption, which contributes to weight loss.
- Mg and K: Maintain blood pressure levels, which contributes to relaxing blood vessels and reducing high blood pressure.
- Folate: Reduces the occurrence of congenital anomalies in the fetus: is a healthy food choice during pregnancy, due to the high volumes of folate necessary for the healthy development of the fetus, and reduces the risk of developing neural tube defects.

- Mg, Cu, Zn, and Vit. D: Maintain bone health: enhance bone strength, the most important of which are manganese, copper, calcium, zinc, and vitamin D.

20.3 Anti-nutritional Factors in Legume Vegetables

The plant substances that have a negative impact on digestion, nutrient uptake, and metabolism (Soetan 2008) are called as anti-nutritional factors. These substances reduce the absorption of micronutrients from plant-based food products (Gemede and Ratta 2014). Some of the anti-nutritional factors present in legumes are tannins, phytates, trypsin inhibitors, etc. Some of the anti-nutrients possess beneficial properties like antimicrobial or anticancer; such compounds are of increasing interest in the fields of pharmacology and nutrition.

The structures of the anti-nutrients and their chemical properties like heat lability help in knowing which physical process will be most effective in their reduction or removal, thereby alleviating adverse biological effects. The physical and chemical methods adopted to alleviate or reduce anti-nutritional factors include soaking, cooking, germination, fermentation, irradiation, and enzymic treatment. In some cases, a single method may not be effective, so combinations of techniques are used.

Crop	Anti-nutritional factors
French bean	Phaseolin
Garden pea	Phytic acid, trypsin inhibitors, and tannins
Cowpea	Trypsin inhibitors
Dolichos bean	Tannins, phytic acid, trypsin inhibitors, cyanogens
Cluster bean	Tannins
Vegetable soybean	Trypsin inhibitors, phytic acid, and tannins
Winged bean	Tannin and phytate, cyanide glucosides
Broad bean/faba bean	Tannin/trypsin inhibitors; zero-tannin phenotype is under monogenic inheritance of two complementary and recessive genes *zt-1* and *zt-2* (white-flowered genotypes)

20.4 Role of Vegetable Legumes in Entrepreneurship

20.4.1 Legume Vegetable Seed Production

India is bestowed with various agroclimatic conditions that allow crop production throughout the year at one place or the other. Vegetable legumes are an important source of nutrition to ever-growing population in India. Consumption of vegetable legumes has increased over time. Hence, seed production of legume vegetables has gained importance on a commercial scale. Hence, one can take up seed production in legume crops, like French bean, garden pea, cowpea, Dolichos bean, and other legume vegetables to become an entrepreneur in legume seed production.

Initial impetus to the vegetable variety development was from public institutes. Several high-yielding varieties in many crops were released including some with disease resistance. The institutions continue to develop and release new varieties and hybrids. Popular varieties released by the institutes are produced and marketed by many small and medium-sized companies. These include Arka Komal in French beans, etc.

India’s seed industry is worth 7000 crores in that vegetable seed industry has 1000 crores share and vegetable legume seeds’ share is 200 crores. The market size has been increasing for quality seeds more than ever. Hence, there is an enormous scope in quality legume vegetable seed production.

Cultural practices for seed production are similar to those of crop production. Legume vegetable crops being self-pollinated require very less isolation distances to avoid mechanical mixtures. Seed production in legume vegetables is not laborious as methods of emasculation and crossing are not involved.

Seed requirement of legume vegetable crops in India (ICAR-IIHR estimation)

Crop	Area (l ha)	Seed rate (kg/ha)	Seed requirement (t)	Actual seed requirement at 30% seed replacement rate (t)
French bean	2.30	30	6900	2070
Pea	5.40	30	16,800	5040
Cowpea	0.60	20	1200	360
Dolichos bean	0.90	30	2700	810
Total				8280

Market size of vegetable legume seeds in India

Crop	Seed requirement (t)	Seed price/kg	Price in crores (Rs)
French bean	2070	300	62.1
Pea	5040	200	100.8
Cowpea	360	500	18.0
Dolichos	810	300	24.3
Total			205.5

Varieties released from ICAR-IIHR, Bengaluru in legume vegetables

Crop	No. of varieties	Varieties	Variety pics
French bean (bush type)	6	Arka Arjun, Arka Komal, Arka Sharath, Arka Suvidha, Arka Anoop, and Arka Bold	 Arka Komal Arka Komal
French bean (pole type)	1	Arka Sukomal	 Arka Sukomal Arka Sukomal
Garden pea	12	Arka Chaitra, Arka Uttam, Arka Tapas, Arka Priya, Arka Ajith, Arka Sampoorna, Arka Pramodh, Arka Nirmal, Arka Harini, Arka Apoorva, Arka Karthik, and Arka Mayur	 Arka Apoorva Arka Apoorva
Dolichos bean (bush type)	5	Arka Jay, Arka Vijay, Arka Soumya, Arka Sambhram, and Arka Amogh	
Dolichos bean (pole type)	08	Arka Swagath, Arka Prasidhi, Arka Bhavani, Arka Visthar, Arka Pradhan, Arka Krishna, Arka Adarsh, and Arka Supriya	 ArkaVisthar Arka Visthar
Cowpea	3	Arka Samrudhi, Arka Suman, and Arka Garima	 Arka Samruddhi Arka Samruddhi

Seed production details in various legume vegetables

Sl. no.	Crop	Seasons	Spacing	Isolation distance (m)	Seed rate (kg/ha)	Fertilizer dose (N:P:K/ha)	Seed yield q/ha
1	French bean	Kharif, rabi	Bush type: 60 × 10 cm Pole type: 200 × 30 cm	FS: 50 m CS: 25 m	Bush type: 40 kg/ha Pole type: 6 kg/ha	Bush type: 62: 50:70 kg/ha Pole type: 62: 50:70 kg/ha	15–20 q/ha
2	Garden pea	Kharif, rabi	Early vars: 30 × 7.5 cm Mid-late vars: 60 × 7.5 cm	FS: 10 m CS: 5 m	Early vars.: 120–150 kg/ha Mid-late vars: 60–75 kg/ha	25:75:60 kg/ha	20 q/ha
3	Dolichos bean	Kharif, rabi	Bush type: 60 × 10 cm Pole type: 100 × 75	FS: 10 m CS: 5 m	Bush type: 60 kg/ha Pole type: 30 kg/ha	25:60:50 kg/ha	15–20 q/ha
4	Cowpea	Kharif, rabi	60 × 15 cm	FS: 10 m CS: 5 m	Bush type: 25 kg/ha Pole type: 10–12 kg/ha	25:60:50 kg/ha	10–12 q/ha
5	Vegetable soybean	Kharif, rabi, and summer	40–50 × 10–15 cm	FS: 100 m CS: 50 m	60–80 kg/ha	20:60:80 kg/ha	10 q/ha
6	Winged bean	Kharif, rabi	100 × 25–75 cm	–	–	40:100:40 kg/ha	15–15 q/ha
7	Cluster bean	Kharif, rabi	45 × 10 cm	–	10–15 kg/ha	25:50:50 kg/ha	20 q/ha
8	Broad bean	Kharif, rabi	60–90 × 15 cm	–	70–100 kg/ha	20:50:40 kg/ha	10–12 q/ha

FS foundation seed, *CS* certified seed

20.5 Seed Village Concept: A Source of Higher Income to Farmers

Seed village concept is to promote the quality seed production of foundation and certified seed classes. The area which is suitable for raising a particular crop will be selected and raised with single variety of a kind. Suitable area for seed production will be identified by the scientists. The foundation/certified seeds or university-labeled seeds will be supplied by the university through Krishi Vigyan Kendras (KVKs) and research stations at 50% subsidy cost to the identified farmers in the area.

Increased income from seed village concept intervention vis-a-vis commercial crop production during 2013–2014 up to July 2018

Year	Number of farmers benefitted	Total area covered (ac)	Net income through commercial crop production (Rs. in lakhs)	Net income/ acre through commercial crop (Rs. in lakhs)	Net income through seed production (Rs. in lakhs)	Net income per acre through seed production (Rs. in lakhs)	Percent increase in farmer's income
2013–2018	80	143.17	62.77	0.44	122.16	0.85	94.62

- Prior to the adoption of seed village concept, the average income generated by cultivation of vegetables was Rs. 44,000/acre.
- Intervention of seed village concept in these farmers' field has resulted in average net income of Rs. 85,000/acre, which amounts to 94% increased income as compared to commercial vegetable production.

20.5.1 Processing in Garden Pea

Urban population in India has been increasing the consumption of frozen processed food. There is a huge demand for fresh garden pea as well as frozen peas in India. The fresh peas are available only during winter months but are required throughout the year. Also, pea cultivation is restricted to few states. Hence, the demand and supply gap of fresh garden pea can be met through frozen garden pea. The size of Indian frozen vegetable market is 9219.60 tonnes. Out of a total Indian frozen vegetables' sale, frozen peas amount to 75%, i.e., 6915 tonnes (Euromonitor International Database 2010). The frozen food market is at an emerging stage in India. So, farmers can venture into frozen pea marketing and export.

Export of processed legume vegetables from India (DGCIS Annual Report n.d.)

Product	2017–2018		2018–2019		2019–2020	
	Quantity (Mt)	Rs. in crores	Quantity (Mt)	Rs. in crores	Quantity (Mt)	Rs. in crores
Peas (dried, shelled, whether or not skinned/split)	4441.48	12.69	2069.94	8.03	3174.70	8.89
Vegetable cowpea (fresh)	824.82	5.07	3695.23	19.98	3449.89	21.17
French bean (fresh pods)	788.54	6.11	2693.89	16.61	3540.42	18.56
Importing countries	I—USA, II—UK, III—Germany, IV—Australia		I—USA, II—UK, III—Germany, IV—Russia		I—USA, II—UK, III—Germany, IV—Thailand	

20.5.2 Cluster Bean Gum (Guar Gum) Industry

Guar gum is the gum derived from seeds of the cluster beans. It is the ground endosperm of the seeds from *Cyamopsis tetragonoloba* (L.) Taub., mainly consisting of high-molecular-weight (50,000–8,000,000) polysaccharides composed of galactomannans; the mannose:galactose ratio is about 2:1. The seeds are crushed to eliminate the germ, and the endosperm is dehusked, milled, and screened to obtain the ground endosperm (native guar gum). The gum may be washed with ethanol or isopropanol to control the microbiological load (washed guar gum). It has good solubility, good thickening, and good hydrogen-bonding property.

Guar gum is used in food emulsifier, food additive, food thickener, and other guar gum products. The unique binding, thickening, and emulsifying quality of guar gum powder has gained importance in the international market. The consumption of guar gum by the oil drilling industry was limited to around 30%. But at present, the scenario has changed and the major consumer of guar gum is the oil drilling industry while the demand from the food industry has reduced to around 20%. Since there is a huge demand for guar gum in national and international markets and 80% of the total guar gum is produced in India, one can consider it as an option for setting up processing and export business.

Guar gum-importing countries from India (DGCIS Annual Report n.d.)

Year	Total export		Importing countries
	Quantity (lakhs)	Value (Rs. in crores)	
2020–2021	1.54	1204.54	I—USA (20477.52 Mt), II—Russia (16057.97 Mt), III—Germany (16760.30 Mt), China (11073.70 Mt), Norway (18537.07 Mt), UK, Australia, Netherlands, Canada
2019–2020	3.82	3261.60	I—USA (99210.73 Mt), II—Russia (28538.52 Mt), III—Norway (56823.50 Mt), Germany (21030.92 Mt), China (21551.81 Mt), Netherlands, UK
2018–2019	5.13	4707.05	I—USA (162729.13 Mt), II—China (66292.66 Mt), III—Russia (27459.78 Mt), Norway (73369.88), Germany (22712.86 Mt), Netherlands, Argentina

20.6 Conclusion

Legume vegetable crops are important sources of carbohydrates and protein. Pea, cowpea, and beans (Indian bean and French bean) are the important leguminous vegetables. The other beans of lesser economic importance include cluster bean, broad bean, lima bean, winged bean, etc. Pea and broad beans are cool-season crops, while other beans are warm-season crops and all are direct-seeded crops. Legume vegetable crops are valued for their nutrition, viz. protein (1.7 g/100 g in French bean to 29.65 g/100 g in winged bean), carbohydrate (4.5 g in French bean to 58.29 g/100 g in broad bean), dietary fiber (2.0 g/100 g in cowpea to 25.9 g/100 g in winged bean), minerals (Fe, P, Ca, and K), and vitamins (Vit. A, B, and C), and their corresponding therapeutic value, viz. antidiabetic (French bean, Dolichos beans), anti-cancerous (French beans), and antioxidant properties (winged beans). The legume vegetable seed market is approximately Rs. 205.5 crores per annum in India (ICAR-IIHR estimation), and predominantly all are self-pollinated; hence, seed production is comparatively easy and can be taken up on wider geographical areas. Seed production in legume vegetable crops can double the farmers' income in comparison to vegetable production, and through the seed village concept, 94% increase in income for the beneficiary farmers is estimated.

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21 Underexploited Vegetables of Coastal India for Nutrition and Entrepreneurship

T. Pradeepkumar and K. I. Divya

Abstract

A healthy living primarily depends on the food we consume, and it should be capable of providing the proportionate nutrients for supporting a balanced diet. Nowadays, food consumption of people is showing a changing pattern from the traditional nutrient-rich diets to processed, energy-dense and micronutrient-poor foods, which are the main reasons behind obesity and diet-related chronic diseases, and this leads to the 'triple burden' of malnutrition-undernourishment, micronutrient deficiencies and obesity. Micronutrient deficiencies are referred to as 'hidden hunger', and vegetables are considered foremost to combat these deficiencies as it is capable of providing ample vitamins, minerals, dietary fibres and phytochemicals. The per capita net availability of vegetables is estimated as 272 g/day as compared to the daily recommendation of 350 g by the Indian Council of Medical Research, which shows a wide gap between the availability and requirement. This nutritional insecurity may be minimized by the exploitation of lesser known indigenous vegetables otherwise known as underutilized vegetable crops, which are a rich pack of nutrients and bioactive principles.

Keywords

Underutilized · Indigenous vegetables · Malnutrition · Bioactive compounds · Deficiency

T. Pradeepkumar (✉) · K. I. Divya
Department of Vegetable Science, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala, India

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21.1 Introduction

A well-balanced diet is essential for a healthy living, which merely depends on the daily intake of required nutrients in adequate proportion. But the changing life pattern of people is showing a drift from the traditional diets based on minimally processed foods to highly processed, energy-dense, micronutrient-poor foods and drinks, which lead to obesity and diet-related chronic diseases. This nutrition transition is leading to the phenomenon known as ‘triple burden’ of malnutrition—undernourishment, micronutrient deficiencies and obesity. Undernourishment and obesity are the direct results of improper or excess consumption of energies, and the signs of this malady are easily visible, whereas micronutrient deficiencies are considered as ‘hidden hunger’. According to food guide pyramid, which is the representation of the optimal number of servings to be eaten each day from each of the different basic food groups, vegetables are the first and foremost component to be included in the daily diet for meeting 30–60% of calories and the rest can be consumed from fruits, pulses, seeds and nuts, whole grains, dairy and animal products and processed products. Hence, vegetables are considered essential for a well-balanced diet as they supply energy, protein, vitamins, minerals, dietary fibres and phytochemicals that reduce the lifestyle degenerative diseases, viz. diabetes, cardiovascular diseases, hypertension and cancer.

Vegetable production in India showed a remarkable growth because of large-scale adoption of technologies and varieties/hybrids by farmers. The major portion of this production was contributed by only few major vegetables though diverse agro-climatic conditions of India permit cultivation of more varied vegetables. Though there has been an increasing trend in vegetable production over the years, availability to all communities of people is doubtful. The statistics by Horticultural Statistics division during 2016 found that the nutritional intake of these vegetables is higher among urban population than that of rural population and per capita net availability of vegetables is 286 g/day as compared to the daily requirement of 350 g by the ICMR. Further, the eating habit of the people belonging to different realms varies depending upon different factors, viz. socio-economic background, price, geography, environment and season. The affordability of rural population to a wide range of nutritious foods is low. Therefore, poor people disproportionately suffer from micronutrient deficiencies and bear the long-term negative effects of mineral and vitamin deficiency. The alternative to this nutritional insecurity is the exploitation of lesser known vegetables, which come under the category of underutilized vegetable crops.

21.2 Underexploited Vegetables

The vegetable crops which are neither grown commercially on large scale nor traded widely may be termed as underutilized vegetable crops. They are undervalued or neglected ‘minor crops’ that are already cultivated, but are underutilized regionally or globally with low global production and market value. Thus, the species whose potential is not fully exploited are termed as underutilized vegetables. The cultivation of these vegetables will meet the shortage of per capita consumption availability, solve the nutritional problems, generate employment and ensure increase in the income of rural people.

21.3 Underutilized Vegetable Crops: Features

- Are adapted to specific agro-ecological niches and marginal land
- Have a scientific or ethnobotanical proof of food value
- Are recognized to have indigenous uses in localized areas
- Are highly nutritious and/or have therapeutic medicinal or therapeutic properties or other multiple uses
- Either have been cultivated in the past or are only being cultivated in a specific geographical area
- Are produced in traditional production system with little or no external inputs
- Have little attention from national research, extension services, policy and decision makers, technology providers and consumers

21.4 Importance of Underutilized Vegetables

- Nutritionally rich—rich source of carbohydrates; fats; proteins; energy; vitamins A, B1, B2, B3, B6, B9, B12, and C; minerals (Ca, P, K, Fe, Zn); and dietary fibre
- Prevent and cure diseases like kwashiorkor, marasmus, night blindness, anaemia, diabetes, cancer, hypertension and hidden hunger
- Can be included in our diet to meet the micronutrient requirement (hidden hunger), which reduces obesity, heart diseases, type 2 diabetes and cancers
- Keep the population healthy and nutritionally secure rather than costly off-season vegetables
- Are easy growing, highly adapted to the environment, resistant to pest and disease and acceptable to local taste
- Enhance environmental services by filtering and processing toxic substances, preventing soil erosion and restoring degraded soils
- Might be marketed in new ways as novel food and help to raise incomes of rural communities
- Can be the raw materials for bioactive compounds and thus open way to new ventures

21.5 Diversity in Underutilized Vegetable Crops

- **Leafy types**
  Major leafy vegetables come under families Amaranthaceae, Cucurbitaceae, Leguminosae, Chenopodiaceae, Cruciferae, Labiatae, Leguminosae, Liliaceae, Polygonaceae, Portulacaceae, Malvaceae and Umbelliferae.
- **Tender fruits/pods**
  Tender fruits/pods belonging to groups *Abelmoschus, Benincasa, Momordica, Coccinia, Cucurbita, Luffa, Solanum, Trichosanthes, Canavalia, Dolichos, Mucuna* and *Vigna* are eaten in cooked form as vegetable.
- **Edible sprouts**
  Edible sprouts are boiled/fermented and made into soup or eaten as vegetable. Several of these are also pickled and used as preservatives. For example, bamboos—young culms of *Bambusa, Cephalostachyum, Dendrocalamus, Phyllostachys* and *Sinocalamus* species—are boiled/fermented and made into soup or eaten as vegetable. Several of these are also pickled and used as preservatives.

21.6 Nutritional Importance of Underexploited Vegetable Crops

Indigenous vegetables can play an important part in alleviating hunger and malnutrition. The importance of underutilized vegetable crops can be realized from two standpoints such as nutritional and economic points of view. Underexploited vegetables are rich in protein, vitamin A, vitamin C, potassium, calcium, thiamine, riboflavin, folate, antioxidants and dietary fibre. It offers health benefits such as improving digestion and eyesight, balancing cholesterol levels, treating anaemia, fighting free radicals, supporting cardiovascular health, promoting weight loss, boosting energy and immunity levels and preventing skin disorders. Hundreds of indigenous vegetables are known to have food value, but the nutrient content of many of these leafy vegetables is undocumented and assessment of their intake patterns is not available. Besides their nutritional values, they are considerable for their medicinal importance. Laboratory studies of these plants have shown that most of these plants have antioxidant property followed by anti-inflammatory, antidiabetic, anticarcinogenic, antibacterial and hepatoprotective properties. As these vegetables are cheap, locally available and locally acceptable, it is an ideal alternative for costly off-season vegetables for maintaining the population healthy and nutritionally secure. The nutritional value as well as the medicinal properties of different underexploited vegetable crops are given in Table 21.1, and the micronutrient content of different underexploited leafy vegetables is summarized in Table 21.2.

Table 21.1 Nutritional and medicinal properties of underexploited vegetable crops

Common name	Scientific name, parts used as vegetable and propagules	Nutritional and medicinal properties
Green amaranth/ pigweed	*Amaranthus viridis* Amaranthaceae Leaves and young shoots Seed propagation	Leaves have antioxidant activity (28.92 μg/ mL), diuretic, blood purifier, relieve heart troubles, lactagogue
Prickly amaranth	*Amaranthus spinosus* Amaranthaceae Leaves and tender branches Seed propagation	Good sources of calcium, vitamin A and iron. Used as laxative and antidiabetic and in the treatment of urinary problems, colic pain and leucorrhoea The ashes of the plant are used in dyeing, and the roots are used in native medicine
Basella spp.	*Basella alba*, *B. rubra* Basellaceae Leaves and tender branches Seed as well as cuttings	Leaves contain folic acid, antioxidants and essential amino acids, arginine, histamine, lysine and methionine. Treatment of jaundice, tuberculosis, cracking of mouth corners, sleeplessness and epilepsy. Kidney stones are dissolved if soup is taken daily Fresh leaf juice mixed in tender coconut water to control blood pressure, cardiac and kidney failure
Chekurmanis	*Sauropus androgynus* Euphorbiaceae Fresh tender leaves and young shoots Stem cuttings and seed	Leaves rich in protein, fibre, iron, calcium and zinc and have antioxidant property (vitamins A and C). Multivitamin multi-mineral green Dark-green leaves provide a rich source of chlorophyll (beneficial for blood circulation and for regular bowel elimination) Micronutrients and photochemical rich: antioxidant properties (heart disease and certain types of cancer). Lower blood pressure, cure anaemia Leaves have antibacterial activity against *Klebsiella pneumoniae* and *Staphylococcus aureus*
Agathi	*Sesbania grandiflora* Leguminosae Leaves, tender pods and flowers Seed propagated	Leaves rich in vitamins A, C and B complex, flower rich in protein content Important source of iodine (2.3 mg/100 g). Regular consumption recommended for goitre patients. It contains a wide range of essential amino acids, viz. arginine, histidine, lysine, tryptophan, phenylalanine, methionine, cystine, threonine, leucine, isoleucine and valine
Spreading hog wood	*Boerhavia diffusa* Nyctaginaceae Leaves are edible Seed propagated	Leaves—blood purifier, cough, asthma, dropsy, chest pain, piles, jaundice, removal of thread worms and urinary disorders Roots are used as a laxative, diuretic, emetic in large doses, antivenom, and in the treatment of heart disease. Roots have an expectorant action, thus used in the treatment

(continued)

Table 21.1 (continued)

Common name	Scientific name, parts used as vegetable and propagules	Nutritional and medicinal properties
		of asthma, cough, stomach and intestinal colic, haemorrhage, oedema, anaemia, eye disease, liver ailments
Horse purslane	*Trianthema portulacastrum* Aizoaceae Leaves and shoots Seed propagated	Leaves are diuretic, used in oedema and dropsy
Roselle/Indian sorrel	*Hibiscus sabdariffa* Malvaceae Young leaves, tender stems Seed propagated	It possesses acidic taste and is used in curries Leaves are rich source of iron, vitamins, pectin, folic acid and antioxidants The fleshy calyxes are rich in acids and pectins (3.19%), used in jellies, jam syrup and wine. In Egypt, dried roselle calyx is used to prepare 'Roselle tea'
Ran bhindi	*Hibiscus surattensis* Malvaceae Leaves and tender stem Seed propagated	Acid flavour and mucilaginous texture Used as salads or cooked as a potherb, put in curries, used for flavouring Red fleshy calyxes are used for making tea, which has numerous medicinal properties The mucilaginous leaves are added to sauces, soups, etc. as a thickener Plant is regarded as a tonic for heart and stomach and used for the treatment of hypertension as well as for its cardio-protective effects
Black night shade	*Solanum nigrum* Solanaceae Tender leaves along with branches Seed propagated	Plant extract used in the treatment of stomach problems, mouth ulcers, urinary problems and menstrual problems. Leaves were found to be richer in polyphenols Used as both food and medicine, considered as antioxidant, anti-inflammatory, diuretic, antipyretic, anticancer agent against digestive system cancer Good for cooling hot inflammation, ringworm ulcers, gout and ear pain Whole herb is used for colds and fever, sore throat, chronic bronchitis
Water hyssop	*Bacopa monnieri* Scrophulariaceae Whole herb as vegetable Stem cuttings	Known for enhancing memory, used as blood purifier and diuretic, curing diarrhoea, bad ulcers, tumours, indigestion, inflammation, anaemia, depression and fever It is used in formulations for the management of mental conditions including anxiety, lack of concentration, as a diuretic and as an energizer for the nervous system and the heart
Ceylon spinach	*Talinum triangulare* Portulacaceae	

(continued)

Table 21.1 (continued)

Common name	Scientific name, parts used as vegetable and propagules	Nutritional and medicinal properties
	Leaves and shoots Seeds and stem	Good for diabetic patients. It is mineral rich Excess use not recommended due to the presence of oxalates and HCN content
Indian pennywort	*Centella asiatica* *Apiaceae* Leaves and branches Runners	Leaves improve intelligence and memory Used against skin diseases, ulcers, dysentery, fevers and wounds Anti-inflammatory, antiasthmatic, antioxidative, anticancer, hepatoprotective, anti-tumorous and neuroprotective activities The medicinal values are due to major bioactivities contributed by the triterpene saponins and their sapogenin derivatives (centellosides)
Sickle senna	*Senna tora* Leguminosae Leaves and tender branches Seed propagated	Higher protein, fibre and vitamin C content Significantly low nitrate and oxalate content than amaranth Whole plant along with roots used for the treatment of hepatitis, diabetes and skin diseases and improves vision
Coffee senna	*Senna occidentalis* Leguminosae Young leaves, flowers and immature seed pods Seed propagated	Blood purifier, antidiabetic, expectorant, stomachic and liver tonic
Sessile joyweed	*Alternanthera sessilis* Amaranthaceae Leaves and tender branches Seed propagated	Improves vision, used against diabetes, hepatitis, bronchitis, mouth ulcers, burns, eye diseases, etc. Used as a galactagogue, to treat hypertension (high blood pressure), gastrointestinal issues, chronic liver congestion
Portulaca/ purslane	*Portulaca oleracea* Portulacaceae Stem cuttings and seed Seed or cuttings	Contains more omega-3 fatty acids than other leafy vegetables Two types of betalain alkaloid pigments, viz. reddish and yellow betaxanthins These pigments are potent antioxidants and have antimutagenic properties
African coriander	*Eryngium foetidum* Apiaceae Leaves are used as a spice Seed propagated	Used for seasoning of meats, vegetables, chutneys and soup. Use is in chutneys as an appetite stimulant. Rich in phytonutrients, flavonoids and phenolic compounds Used as a tea for flu, diabetes, constipation and fevers Anticonvulsant and has antioxidant activity property
Indian sorrel	*Oxalis corniculata* Oxalidaceae Leaves Seed and runners	Leaves are a good source of vitamin C (125 mg/100 g) and carotene (3.6 mg/100 g) Prevents digestive anomalies like acidity, flatulence, constipation

(continued)

Table 21.1 (continued)

Common name	Scientific name, parts used as vegetable and propagules	Nutritional and medicinal properties
		Anthelmintic activity, curbs excessive thirst caused by diabetes or severe heat It prevents scurvy due to high vitamin C content
Chaya mansa	*Cnidoscolus aconitifolius* Euphorbiaceae Young shoots and tender leaves Stem cuttings	Leaves taste like spinach. Chaya leaves reported superior to other leafy green vegetables such as spinach, amaranth, Chinese cabbage and lettuce Hypoglycaemic effect, improves blood circulation, lowers cholesterol Prevents varicose veins and haemorrhoids
Prickly chaff	*Achyranthes aspera* Amaranthaceae Tender leaves Seed propagation	Medicinal values are for curing liver problems, asthma and ear problems It is widely used in homeopathic medicine
Vegetable fern	*Diplazium esculentum* Athyriaceae Tender leaves Divisions, spores	Leaf decoction is used for expectoration of blood and coughs and urinary problems
Ceylon slitwort	*Leucas aspera* Lamiaceae Leaves and flowers Seed propagated	Leaf extract used against fever cough and skin problems. Juice of tender branches used against jaundice. Whole-plant extract improves resistance power of the body It is antihyperglycaemic
Lettuce tree	*Pisonia alba* Nyctaginaceae Leaves are edible Stem cuttings	Leaves are used as analgesic, anti-inflammatory, diuretic, hypoglycaemic agent Used in the treatment of ulcer, dysentery, rheumatism and arthritis
Water spinach	*Ipomoea aquatic* Convolvulaceae Young leaves and shoots Vine cuttings	Rich in provitamin A, amino acids, organic acids and other minerals It is good antioxidant, reduces cholesterol and blood pressure, prevents indigestion and anaemia, good for liver
Taro	*Colocasia esculenta* *C. antiquorum* Araceae Tender leaves along with stalk Corms for propagation	Cooked leaves nutritious like spinach. Cooking will get rid of the irritating oxalate crystals. Good for stomach problems The differences of *antiquorum* genotypes from *esculentum* are relatively smaller central corm and well-developed side cormels Corms are rich in starch good energy source and alternate for cereals, low in protein and fat, but vitamins and minerals more compared to other root crops Taro foods are useful to persons allergic to cereals and sensitive to milk
Bathua	*Chenopodium album* Chenopodiaceae	Leaves are a rich source of minerals and protein

(continued)

Table 21.1 (continued)

Common name	Scientific name, parts used as vegetable and propagules	Nutritional and medicinal properties
	Leaves and young shoots Seed propagated	Laxative, anthelmintic for hookworms and roundworms, blood purifier, prevent dysentery, diarrhoea, oedema, piles
Sweet potato	*Ipomoea batatas* Convolvulaceae Tender leaves Vine cuttings	Rich in antioxidants, vitamin C, vitamin A, thiamin, riboflavin, niacin and folic acid Antidiabetic, treat anaemia, hypertension, oral diseases Offers protection from cancer, allergies, ageing and cardiovascular problems
Kattupaval	*Momordica sahyadrica* Cucurbitaceae Leaves and fruits Seed propagated	Leaves and fruits used in the treatment of liver problems and stomach problems
Winged bean	*Psophocarpus tetragonoloba* Leguminosae Tender pods, shoots, flowers, seeds, leaves and tubers are edible Seed propagated	Known as vegetable of the twentieth century/ supermarket on stalk Rich in minerals, vitamins, amino acid lysine. Counter the problems of protein-energy malnutrition. Beans are also rich in carbohydrates and vitamin A (300–900 IU) High content of niacin present in winged beans helps in reducing the formation of blood clots by reducing platelet aggregation. Reduces the risks of cardiovascular disorders
Sword bean *Jack bean*	*Canavalia gladiata* *Canavalia ensiformis* Leguminosae Tender fruits Seed propagated	Rich in different nutrients, such as carbohydrates, proteins, vitamins and minerals It has anti-inflammatory, hepato-protective and anti-angiogenic activities Good sources of natural antioxidant phenolics, hence have potential health benefits against oxidative stress-related chronic diseases
Clove bean	*Ipomoea muricata* Convolvulaceae Tender fruits Seed propagated	Cultivation is very simple and not season bound. It can be cultivated year round It is free from the attack of insect pests Fruits contain fibre, vitamin C, potassium and calcium Powdered clove beans are known as a remedy to fever, plants' juice is sprayed to kill bugs
Pointed gourd	*Trichosanthes dioica* Cucurbitaceae Tender fruits Propagation by roots and cuttings	Tender fruits are used for cooking as vegetable. Fruits have vitamin A and vitamin C Several medicinal properties as diuretic and laxative properties
Giant granadilla	*Passiflora quadrangularis* Passifloraceae	Fast-growing tropical vine with fleshy tubers Immature fruits cause relief from stomachic disorders and scurvy

(continued)

Table 21.1 (continued)

Common name	Scientific name, parts used as vegetable and propagules	Nutritional and medicinal properties
	Immature fruits Seeds and cuttings	Fruits—treatment of headaches, asthma, diarrhoea, dysentery, neurasthenia and insomnia. The roots of old plants are baked or roasted and eaten like yams Root is diuretic, emetic, narcotic and vermifuge. It contains passiflorine, an anthelmintic agent
Breadfruit	*Artocarpus altilis* Rutaceae Immature fruit Seeds, root suckers or cuttings	Fast-growing evergreen tree in humid and wet areas Mature sweet ripe fruit is eaten as dessert and used to make pies, cakes and other sweets Fruit can be roasted, boiled, dried, pickled, used in bread making
Sweet gourd	*Momordica cochinchinensis* Cucurbitaceae Immature fruit Seed propagated	Fruit aril—orange-reddish colour—beta-carotene and lycopene, used as food colour Fruits are rich in protein, vitamin C and vitamin A Fruits and leaves have medicinal properties to cure ulceration, lumbago and fracture of bone. Roots are rich in saponin and bessisterol, which may be used in pharmaceutical industries. Seeds are used to treat swelling, ulcer and abscesses
Dioscorea	*Dioscorea* alata *D. esculenta* *D. rotundata* Dioscoreaceae Tubers	Rich in carbohydrate and calorie. Considered as substitute for cereals. Withstand adverse soil and climatic conditions especially drought. Flexible to thrive in mixed farming systems Pink flesh and skin colour in yams are mainly due to anthocyanin. It provides valuable raw material for various products. Excellent source of carbohydrate, hence a number of chemical and industrial products like sweeteners (maltose and fructose), modified starch, fermented food products (alcohol, organic acids) *Steroidal saponins*, viz. diosgenin and dioscorin, precursor used for the synthesis of steroidal drugs, oestrogen and progesterone
Chinese potato	*Solenostemon rotundifolius* Lamiaceae Tubers Tubers and vine cuttings	Tubers are milled into flour and made into various food products Have antioxidant activity, hence potential to mediate cancer cells Low glycaemic index, reduce the risk of diabetes and obesity Absence of gluten, alternative food source for gluten-free food products

(continued)

Table 21.1 (continued)

Common name	Scientific name, parts used as vegetable and propagules	Nutritional and medicinal properties
Arial yam/potato yam	*Dioscorea bulbifera* Dioscoreaceae Edible part—tuber and aerial Bulbils Planting material—aerial Bulbils	Tuber contains dioscorine Used in Indian and Chinese medicine for treatment of gastric cancer, sore throat and carcinoma of rectum Also treating diarrhoea, dysentery syphilis, gonorrhoea, goitre and piles
Water lily	*Nymphaea* spp. Nymphaeaceae Stems, young leaves, lower buds, flower stalks and rhizomes Seed propagated	Rhizomes are cool, sweet and bitter, and tonic is useful in treating diarrhoea, dysentery and general debility. The flowers are astringent and cardiotonic. Seeds are sweet, stomachic and restorative and are also used as treatment for gastrointestinal disorders and jaundice
Lotus	*Nelumbo nucifera* Nymphaeaceae Tender rhizomes, stems and leaves Seed propagated	Nutritionally, lotus seeds are rich in proteins (10.6–14.8%) and essential minerals Cooked along with other vegetables, soaked in syrup or pickled in vinegar Widely used in folk medicines to treat tissue inflammation, cancer, diuretics and skin diseases and as poison antidote. Different parts of the lotus plant are useful in treatment of diarrhoea, tissue inflammation and haemostasis
Bamboo	*Dendrocalamus strictus* Young shoots Propagation of seeds, rhizome and culm cuttings	Low fats and cholesterol and high amount of carbohydrate, proteins, minerals and dietary fibres Amino acid content in bamboo shoot is found to be much higher than in other vegetables such as cabbage, carrot, onion and pumpkin

21.7 Entrepreneurship: A Future Treasure

Underutilized vegetable crops are paid little attention or entirely ignored by consumers, agriculture researchers, entrepreneurs and policymakers. Wide acceptability of these crops among the stakeholders depends on the profitability from these crops, and it can be increased by encouraging diversified use of these crops. The multiple roles of wild traditional vegetables as both food and medicinal source have to be recognized. Most of these minor and underutilized crops are very rich in nutrients, natural pigments and starch, which serve as raw materials for food and industrial products. They offer natural antioxidants and bioactive compounds with potential therapeutic value for combating chronic diseases. But future studies are required for the characterization of active compounds and their scientific validation is needed for creating promising leads in the indigenous medicine sector. Thus,

Table 21.2 Nutrient content in underexploited leafy vegetables

Crop	Nutrient content (g/100 g)		Nutrient content (mg/100 g)										B-carotene (µg/100 g)
	Protein	Fibre	P	Ca	K	Na	Fe	Zn	Vit C	B1	B2	Niacin	
Amaranthus viridis	5.2	6.1	52	330			12.7	10	178	0.07	0.22		1725
A. spinosus	3.96	1.47	84	698	588	9.61	15.43	2.35	105.42				3564
Basella sp.	1.3	2.4	35	81	508		4.45	0.25	71	0.03	1.06	0.55	7440
Chekurmanis	6.8	1.4	200	570			28		247	0.48	0.32	2.6	5706
Agathi	8.4	2.2	80	1130			3.9		169	0.21	0.09	1.2	5400
Boerhavia	6.1	0.97	99	667	52.7		18.4		27				4400
Horse purslane	2.0	0.9	30	100			38.5	3.0	70				1900
Roselle	3.0	1.6	93	213			4.8		54	0.17	0.45		2898
Centella	3.17	1.4	58	217	45		13.63	2.03	56.28	0.08	0.19	0.8	613
Black night shade	4.34	1.63	80	346	787	12.29	4.76	1.64	141.56			0.3	2061
Bacopa monnieri	2.1	1.05	16.0	202			7.8		63				
Ceylon spinach	1.91	1.27	290	190	296	3.3	1.36	0.53	175.57				733
Senna tora	5.28	1.76	83	720	820	5.97	6.66	1.4	151				1822
Alternanthera	4.63	2.3	84	199	110.4	18.4	14.57	0.51	48.99		0.14	1.2	1926
Portulaca oleracea	1.92	0.96	40	750	33	10.37	11.88	0.77	38.83				341
Cnidoscolus aconitifolius	6.8	2.0	85	265	217.4		11.4		185	0.12	0.15	1.6	1357
Achyranthes aspera	4.0	1.19	73	430	98.3	3.76	22.6	1.37	43.15				1513
Diplazium esculentum	3.55	1.99	49	112	686	16.0	1.8	0.94	32.03				833
Leucas aspera	2.68	1.42	59	170	374	6.31	3.54	0.66	34.16				1341
Lettuce tree	3.6	0.6	60	170			3.6		165	0.03	0.11	0.2	888
Water spinach	2.6	2.1	39.0	77			1.67		76.3	0.05	0.13	0.9	1890
Colocasia esculenta	2.77	2.28	64	96	266	3.13	3.82	1.26	27.79				908

C. antiquorum	2.67	1.09	30	110	378	2.56	0.57	0.16	66.12				972
Bathua	3.7		80	150			4.2		35	0.01	0.01		1740
Sweet potato	3.75	6.4	144	1300	2642		14.3	3.3	60	0.54	5.5	0.49	3500
M. sahyadrica	2.62	1.37	56	136	496	8.79	5.2	1.68	54.86				1684

underexploited vegetable crops possess great potential that can be exploited for nutritious food products, fortified food items, natural colouring agents, therapeutic use in the pharmaceutical industry and synthesis of powerful and novel drugs. The industrial uses of underexploited vegetable crops are briefed in Table 21.3.

21.8 Constraints for the Development of Underutilized Vegetable Crops

- Lack of awareness among the farming community about the nutritional and medicinal value of underutilized vegetable crops
- Lack of desirable seeds and planting material
- Limited application of advanced on-farm agro-techniques
- Lack of post-harvest management practices
- Limited and inadequate marketing supports and infrastructure facilities for transportation, storage and processing
- Lack of research in areas of developing improved lines with special traits, product diversification and pharmacology
- Poor recognition of these crops in horticulture promotion programmes

21.9 Strategies for the Development of Underutilized Vegetable Crops

- Domestication of potential wild species through homestead cultivation should be encouraged for avoiding overexploitation from natural sources.
- Supports are required in terms of multiplication of planting materials and their distribution besides providing market access through marketing network for perishables.
- More R&D efforts will add substantially to food security and nutrition.
- Breeding for promising selections/varieties with special and desirable characters.
- Documentation of indigenous knowledge and its confirmation through ethnobotanical studies.
- Systematic local specific crop planning in accordance with agro-climatic suitability of the region needs to be developed.
- Emphasis should be given on developing processing units in this area for proper exploitation and better economic returns from these crops.
- Efficient production technology and post-harvest management are necessary to make the commercial cultivation of non-traditional horticultural crops feasible.

Table 21.3 Industrial potential of underexploited vegetable crops

Common name	Nutritional and medicinal properties
Basella spp.	The red fruit juice (betalains) used as ink, in cosmetics and colouring of food in pastries and sweets
Chekurmanis	Leaves contain alkaloid, papaverine (580 mg per 100 g fresh leaf). It is an antispasmodic drug used in the treatment of visceral spasm and vasospasm Green leaves are used for giving light-green colour in pastry and fermented rice
Agathi	Agathi leaf powder is used as a raw material for production of mineral and vitamin supplements. Products containing iron and vitamin are available in the market, e.g. biotin products for strengthening nails and hair and folate supplements
Spreading hog wood	The major active principle present in the roots is an alkaloid, punarnavine Incorporation of root powder in products like fruit and lassi is well acceptable
Roselle/Indian sorrel	Fleshy calyx is rich in acids and pectins (3.19%), used in jellies, jam syrup and wine In Egypt, dried Roselle calyx is used to prepare 'Roselle tea' Roselle is used by food and beverage manufacturers and in the pharmaceutical industry It is a good source of fibre, substitute of jute used for making ropes and cordage
Black night shade	Whole herb is used for colds and fever, sore throat, chronic bronchitis Solanum tablets and leaf powder are available in the market as nutrient supplement
Water hyssop	Numerous food products are available in the market which contains Brahmi as functional food ingredients
Indian pennywort	Bioactive compounds triterpene saponins and their sapogenin derivatives (centellosides) are of pharmaceutical value. Centella was included as herb in the World Health Organization monograph by the WHO as it contains >2% saponins. Due to immense therapeutic potential, the demand of Centella herb is rising in the global herbal market According to the report of the National Medicinal Plant Board (India), it is included in the list of 178 species of medicinal plants that are consumed in quantity >100 MT per year in India. Centella asiatica-based products with different brand names are available in the market as liposomal tablets, powder, cream or tincture
Portulaca/ purslane	Leaves contain omega-3 fatty acids Two types of betalain alkaloid pigments, viz. reddish and yellow betaxanthins. These pigments are potent antioxidants and have antimutagenic properties. Tincture oil, whole-plant powder and capsules are available. Also, it is an ingredient in cosmetic items
African coriander	Essential oil used for seasoning of meats, vegetables, chutneys and soup. Main constituent of essential oil is eryngial, i.e. E-2-dodecenal. Estimated a content of 0.29, 0.20 and 0.18% essential oils in the leaves, fruits and inflorescences
Chaya mansa	Leaf powder as dietary supplement, dried leaves used as tea
Taro	Taro foods are useful to persons allergic to cereals and sensitive to milk. Used as a substitute for cereals in baking products and as an additive to render biodegradable plastic

(continued)

Table 21.3 (continued)

Common name	Nutritional and medicinal properties
Breadfruit	Mature sweet ripe fruit is eaten as dessert and used to make pies, cakes and other sweets Immature fruits are roasted, boiled, dried and pickled and are used in bread making
Sweet gourd	Roots are rich in saponin and bessisterol and are used in pharmaceutical industries
Dioscorea	Excellent source of carbohydrate, number of chemical and industrial products like sweeteners (maltose and fructose), modified starch, fermented food products (alcohol, organic acids) *Steroidal saponins*, viz. diosgenin and dioscorin, precursor for the synthesis of steroidal drugs, oestrogen and progesterone
Chinese potato	Low glycaemic index in tubers, reduces the risk of diabetes and obesity Absence of gluten makes it an alternative food source for gluten-free food products
Arial yam/potato yam	Tuber contains dioscorine Used in Indian and Chinese medicine for the treatment of gastric cancer, sore throat and carcinoma of rectum

21.10 Conclusion

Indigenous vegetables are shade tolerant and well adapted to local climatic conditions and can be grown without much care. They are considered as protective foods since they are rich in micronutrients and bioactive compounds. Though they are potential enough to provide food and nutritional security, they have not been fully exploited. There are different lacunae which interfere the growth and utilization of these crops. Creating adequate awareness among public about these plant species and their food and medicinal value should be the top priority of policymakers, extension workers and researchers. Domestication process of these plants can be intensified through standardization of agronomic practices like selection of propagules. The perishable nature of these vegetables demands comprehensive planning for its growth as a venture depends on allied enterprises like storage, processing and marketing of these crops. Certain traditional vegetables are becoming an increasingly attractive food group for the wealthier segments of the population and are slowly moving out of the underutilized category into the commercial market. This demand has attracted some seed companies to exploit these crops to meet consumer demands, which will create a bright future for these neglected or unforgotten vegetables.


Amarathus viridis


Amarathus spinosus


Sauropus androgynus


Sesbania grandiflora


Talinum triangulare


Boerhavia diffusa


Solanum nigrum


Cassia tora


Portulacca oleraceae


Alternanthera sessilis


Cnidoscolus aconitifolius


Pisonia alba


Diplazium esculentum


Ipomea aquatica


Oxalis corniculata


Senna occidentalis


Momordica sahyadrica


Hibiscus subdariffa


Psophocarpus tetragonoloba


Canavelia gladiata


Canavelia ensiformis


Ipomea muricata


Passiflora quadrangularis


Dioscorea bulbifera

22 Root Vegetables for Nutrition and Entrepreneurship

Pritam Kalia and Raman Selvakumar

Abstract

The nutritional contents of root vegetable crops are important because of their varied food value and extended storage life. Orange carrot is a good source of vitamin A and fibre in the diet. Black carrot is used in the production of *Kanji*, which is said to be a tasty appetizer and rich in anthocyanins. Carrot roots are unique in that they contain a high concentration of carotenoids, as well as terpenoids and polyacetylenes, which give the carrots a characteristic flavour. Radish is primarily cultivated for its thicker meaty root, which is mostly used in salads. These are a good source of glucosinolates, which are the precursor of isothiocyanates. Red radishes are also rich in anthocyanins. Turnip is one of the most significant leaf and root crops cultivated and consumed all over the world. It is low in fat and calorie content, but is a good source of minerals, vitamins, and bioactive compounds and has a high dry matter digestibility, all of which are important for a healthy lifestyle. The value of garden beet is high because of high concentration of red pigments in it, namely betalains. This pigment has outstanding colour values and may be used in both culinary and medicinal applications. Parsnip is high in folate, as well as vitamins B, C, E, and K, all of which are helpful to human health. Rutabagas may help to prevent premature ageing, enhance vision, and promote healthy cell regeneration in our organs and tissues. They are rich in fibre, with each serving supplying more than 12% of the daily need. Root vegetables have plenty of avenues in developing processed products, pigment extraction for edible colours and juice, etc.

P. Kalia (✉)
ICAR-Indian Agricultural Research Institute, New Delhi, India

R. Selvakumar
Center for Protected Cultivation Technology, ICAR-Indian Agricultural Research Institute, New Delhi, India

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Root vegetables are distinguished by a conspicuous, fleshy subterranean structure that may be a root, tuberous root, or a hypocotyl with a taproot developing underneath it, depending upon the crop. The Apiaceae (carrot), Brassicaceae (radish, turnip), and Chenopodiaceae (beet) families produce the most root vegetables. The nutritional content of major root vegetable crops is presented in Table 22.1. The nutritional content of these crops is important because of their varied food value and extended storage life. These thrive in areas where cold night-time temperatures decrease the rate of respiration, allowing stored carbohydrates to be better retained.

22.1 Carrot

Carrot (*Daucus carota* L.; $2n = 2x = 18$), a member of the Apiaceae family, is a cold-season crop cultivated across the globe for its edible storage taproots and is the most significant of all the root crops. Carrots are extensively produced for both the fresh market and processing. It is a good source of vitamin A and fibre in the diet. The black carrot is used in the production of kanji, which is said to be a tasty appetizer. Carrots are classified into two types: tropical and temperate. Tropical plants are annual, while temperate plants are biennial. Carrots come in a variety of colours ranging across black, red, yellow, orange, cream, and white. Carrot also has therapeutic qualities, as shown by the antibacterial characteristics of essential oils derived from carrot roots. The essential oil extracted from carrot seeds is beneficial in renal disorders and dropsy (Chopra 1933; Kirtikar and Basu 1935).

The worldwide market for natural food colourants was estimated at $1.32 billion in 2015 and is projected to increase by 7% per year over the next decade (GNFCM 2018). This rise is in part due to increasing environmental consciousness, health advantages linked with natural pigments, and rising demand for “natural” products (Cooperstone and Schwartz 2016). Major food and beverage businesses are reacting to customer demand by shifting away from synthetic dyes in their goods. However, natural pigment is difficult to utilize because of the interactions with food components, tinctorial strength, poorer stability, and matching of the required colours. Also, manufacturing natural colourant is more costly and needs excellent logistics. Synthetic colourant is a more standardized industrial process, whereas natural colourants have more stages between creation and manufacturing of the raw material, and extraction, dyeing, and packaging. Food colourant industry experts have said that the average cost of natural colours is around five times more than synthetic colours, and in certain cases (e.g. confectionery products), it may be as much as 20 times more expensive. Despite these obstacles, the need for goods that are “clean label”, devoid of artificial ingredients, grows every day. As a result, to

Table 22.1 Nutritional constituents of the major root vegetable crops

Crop	Water (%)	Energy (cal)	Protein (g)	Fat (g)	CHO (g)	Vitamins						Minerals				
						A (IU)	C (mg)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)		Ca (mg)	P (mg)	Fe (mg)	Na (mg)	K (mg)
Carrot	88	42	1.1	0.2	9.7	11,000	8	0.06	0.05	0.6		37	36	0.7	47	341
Radish	95	17	1.0	0.1	3.5	10	26	0.03	0.03	0.3		30	31	1.0	18	322
Turnip	92	30	1.0	0.2	6.6	Trace	36	0.04	0.07	0.6		39	30	0.5	49	268
Beet	87	43	1.6	0.1	9.9	20	10	0.03	0.05	0.4		16	33	0.7	60	335

ensure long-term, sustainable natural colourant production and market viability, it is crucial to use the most modern technology.

Currently, commercially viable anthocyanin-rich extracts are regulated as a colour additive, but not classified as a "natural colour" by the Food and Drug Administration (FDA). These water-based plant extracts with anthocyanins are extensively approved by the European Food Safety Authority (EFSA) for use as colouring material in food, since they are low in toxicity (Wrolstad and Culver 2012) (Commission Directive 1333/2008 (EC)).

Flavonoids are a family of antioxidant flavonoids that create bright hues such as red, purple, and blue. They are found in a wide range of plant tissues, including leaves, roots, flowers, and fruits. However, these natural pigments are subject to breakdown caused by temperature, acidity, and light exposure. This has hitherto restricted their usage as natural colouring agents. Food technology and discovery of novel sources of anthocyanins have led to an increase in their usage, particularly in drinks. The market share of anthocyanins has risen substantially over the past 5 years, to around 9.5% of the market in 2018 (Amir 2019). The "natural" food colour business is expected to rely on anthocyanins, which are fast-growing categories. Because of advances in stability and adaptability, producers will move away from artificial red, purple, and blue colour additives toward anthocyanin-based pigments in food products.

Interest in black or purple carrots as a source of anthocyanins has increased in recent years (Akhtar et al. 2017). Purple carrot extracts have the highest concentrations of anthocyanins, which are often 18 mg/100 g of fresh weight, and have minimal to no off-flavours when compared to other natural pigment sources, such as red cabbage. Additionally, black carrot pigments provide a variety of colours, including blue and purple hues at higher pH levels. This flexibility may be utilized to colour fruit juices, soft drinks, and other food items (Downham and Collins 2000) and may replace FD&C Red 40 (Allura Red) (Wrolstad and Culver 2012; Assous et al. 2014; Wallace and Giusti 2008). During storage and heating treatments, the pigment sources varied; nevertheless, black carrot extract was the most promising pigment source of cobalt blue colours in pectin-stabilized solutions. The relative lack of non-anthocyanin phenolics in purple carrots means that they are a superior source of anthocyanins than grapes (Downham and Collins 2000). A more recent study shows that 80% of customers prefer seeing carrot extract on the product label over synthetic colourant. An in-depth study by Cortez et al. (2016) highlighted many newly patented methods for enhancing natural colourant stability utilizing carrot extracts. Increasing anthocyanin production from carrot plants has also been researched and patented.

The improved stability at higher pH and extended shelf life have made anthocyanins a valuable colourant in the food sector. Purple carrots store a significant amount of mono-acylated anthocyanins (Giusti and Wrolstad 2003; Kammerer et al. 2004), and unlike radishes and red cabbages, these carrots do not need elimination of the sulphur scent (Giusti and Wrolstad 2003). Catalysed by an acyltransferase, the acylation of anthocyanins increases cellular transit and stability, which improves their synthesis, conservation, colour, and shelf-life stability when utilized as a natural dye or pigment (Malien-Aubert et al. 2001; Novotny et al. 2011). Non-acylated anthocyanins are many times more bioavailable than acylated anthocyanins, and carrot-derived anthocyanins may offer health advantages to users. For example, its strong antioxidant capacity has been linked with cancer prevention, better eyesight, lower risk of diabetes, and higher cognitive and memory performance. Estimates by the food industry, based on the yearly requirement of 10,000 tonnes of carrot-derived anthocyanins, put global purple carrot output at about 100,000 hectares.

22.1.1 Nutritional Composition of Carrots

It has been listed among the top ten fruits and vegetables in terms of nutritional content due to the high concentration of bioactive components on the outer surface of the root (cortex) and the presence of a substantial number of vitamins, bioactive components, and minerals (Alasalvar et al. 2001). Carrot roots are unique in that they contain a high concentration of carotenoids, as well as terpenoids and polyacetylenes, which give the carrots a characteristic flavour. Monoterpenoids and sesquiterpenoids are the most prevalent terpenes, whereas falcarinol compounds are the most abundant polyacetylenes. The late development of sugars in the carrot root during growth helps to mask the bitter carrot flavour, but only to a degree. Because of pigmentation differences, roots come in a variety of colours, including red, orange, yellow, purple, black, and white (Haq and Prasad 2014). It is well known that the pigments found in many coloured roots have therapeutic properties that benefit human health. Lutein, present in yellow carrots, for example, assists in the creation of macular pigments, which are required for good eye function (Chrong et al. 2007). Lycopene, which is found in tomatoes and red carrot cultivars (Nicolle et al. 2004), also has considerable singlet oxygen scavenging capacity (de Mascio et al. 1989), and high levels of lycopene in blood plasma have been demonstrated to reduce the risk of developing different malignancies (Giovannucci 1999). The presence of anthocyanins, which are antioxidants, is responsible for carrots' dark or purple colour (Chrong et al. 2007).

The proximate composition of carrot roots was assessed at the Division of Vegetable Science, IARI, New Delhi, India by Kalia and Singh (2016) and the results are provided in Table 22.2. The following proximate content ranges are provided for the several types of carrots: moisture (85.30–86.85 g/100 g), ash (0.92–99 g/100 g), dietary fibre IDF (2.35–2.81 g/100 g), dietary fibre SDF (0.67–1.01 g/100 g), dietary fibre SDF (3.04–3.76 g/100 g), fat (0.18–0.20 g/100 g), protein (0.85–0.95 g/100), and carbohydrate (7.81–9.64 g/100 g).

Vitamins are still a key component of product quality when it comes to carrot types. Also worth noting is that carotenoids are the primary vitamin kinds present in many carrot cultivars. For example, beta-carotene is converted to vitamin A, which aids in the prevention of night blindness and the effectiveness of the immune system (Handelman 2001). Second, α-tocopherol is a vitamin E precursor that is essential in the human body for cell function, gene synthesis, and cell membrane integrity (Luby

Table 22.2 Proximate composition of carrot varieties

Content		Pusa Kulfi	Pusa Meghali	Pusa Rudhira	Pusa Kesar	Pusa Vrishti	Pusa Asita	Range
Moisture (g/100 g)		86.30	86.85	85.55	86.40	85.30	85.46	85.30–86.85
Ash (g/100 g)		0.96	0.94	0.92	0.99	0.96	0.93	0.92–0.99
Dietary fibre (g/100 g)	IDF	2.53	2.35	2.71	2.81	2.35	2.75	2.35–2.81
	SDF	0.79	0.91	0.67	0.80	0.69	1.01	0.67–1.01
	TDF	3.32	3.26	3.38	3.61	3.04	3.76	3.04–3.76
Fat (g/100 g)		0.18	0.19	0.18	0.20	0.18	0.18	0.18–0.20
Protein (g/100 g)		0.89	0.95	0.85	0.92	0.88	0.91	0.85–0.95
Carbohydrate (g/100 g)		8.36	7.81	9.13	7.88	9.64	8.77	7.81–9.64

Fig. 22.1 Nutra-rich varieties of tropical carrot

et al. 2014). Aside from these two vitamins, carrots contain a lot of vitamin C, which is important for blood pressure control, avoiding iron deficiency, and improving immune system performance (Naidu 2003). Aside from that, some carrot cultivars are, especially, high in vitamin B derivatives (thiamine, riboflavin, cobalamin, and pyridoxine) (Hsieh and Ko 2008), and vitamin B is required for cell division, brain function, and digestive system function.

In the Division of Vegetable Science, IARI, New Delhi, India different carrot cultivars (Fig. 22.1) were examined for diverse vitamin profiles by Kalia and Singh (2016), which are presented in Table 22.3. Vitamin B5, vitamin B7, vitamin C, and vitamin K1 are all abundant in all coloured carrot cultivars, while vitamin B3 and α-tocopherols were also found in significant amounts. Pusa Asita (1621.14 mg/100 g) has the highest vitamin C content, followed by Pusa Rudhira (9341.9 mg/100 g), Pusa Meghali (8754.9 mg/100 g), Pusa Vrishti (7610.3 mg/100 g), Pusa Kesar (7543.1 mg/100 g), Pusa Kulfi (6538.8), and Pusa Rudhira (9341.9 mg). Vitamin B7 is found in the highest concentrations in the Pusa Kesar carrot variety (9.86 mg/100 g), followed by Pusa Kulfi (6.43 mg/100 g), Pusa Meghali (6.43 mg/100 g), Pusa Asita (5.27 mg/100 g), and Pusa Rudhira (4.83), while vitamin B3 was highest in Pusa Meghali (0.95 mg/100 g).

Table 22.3 Profiling of vitamins in carrot varieties

Vitamins	Range	Pusa Kulfi	Pusa Meghali	Pusa Rudhira	Pusa Kesar	Pusa Vrishti	Pusa Asita
Vit B_1 (mg/100 g)	0.05–0.07	0.06	0.05	0.05	0.07	0.05	0.05
Vit B_2 (mg/100 g)	0.04–0.06	0.05	0.06	0.05	0.04	0.05	0.05
Vit B_3 (mg/100 g)	0.62–0.95	0.83	0.95	0.62	0.63	0.69	0.95
Vit B_7 (mg/100 g)	4.83–9.86	6.43	6.10	4.83	9.86	4.91	5.67
Vit B_5 (μg/100 g)	1516.8–1779.9	1623.39	1673.50	1516.87	1779.92	1615.31	1621.14
Vit C (μg/100 g)	6538.8–16,187.0	6538.8	8754.9	9341.9	7543.1	7610.3	16,187.0
D_2 (μg/100 g)	1.07–1.5	1.21	1.53	1.08	1.16	1.38	1.07
Vit K_1 (μg/100 g)	4.70–10.9	6.70	6.80	10.70	4.70	6.00	10.90
α-Tocopherols (mg/100 g)	0.02–0.03	0.03	0.02	0.03	0.02	0.02	0.03
γ-Tocopherols (mg/100 g)	0.02–0.04	0.04	0.02	0.04	0.04	0.03	0.04
α-tocotrienol (mg/100 g)	0.01–0.02	0.02	0.02	0.01	0.01	0.01	0.01

22.1.2 Carotenoids in Carrots

Carotenoids are a class of isoprenoids with 40 carbon atoms that include, among other things, carotenes and xanthophylls that have not been oxygenated. They can be found in all green plants, animals, microbes, and fungus and are extensively dispersed throughout nature. These pigments, known as carotenoids, are produced in plants and play an important role in the plant's growth and development as accessory pigments that assist collect light and protect the plant from photooxidative stress (Cazzonelli and Pogson 2010; Della Penna and Pogson 2006; Lu and Li 2008; Nisar et al. 2015). These products of the carotenoid pathway may affect plant growth and flavour as well as mycorrhizal connections (Cazzonelli and Pogson 2010; Della Penna and Pogson 2006). Non-photosynthetic tissues in plants benefit from carotenoids' bright colour because it attracts animals that help pollinate the plants and spread seeds (Simkin et al. 2004; Walter et al. 2007). Animals, including humans, must get carotenoids from food since they cannot generate them on their own, with a few exceptions. Several carotenoids included in diet, such as alpha- and beta-carotene, may be transformed to vitamin A by enzymatic means. They are the sole source of vitamin A for immunological function, eyesight, development, and reproduction. The immune system, retina, and proper reproductive function all depend on vitamin A, which is essential for all the three. In addition to cancer prevention and therapy, these and other carotenoids in food, such as lutein and lycopene, reduce the risk of osteoporosis, macular degeneration, and heart disease (Tanumihardjo 2012). As a plant grows and develops, the amounts and compositional profiles of carotenoids alter dramatically across identical tissues and organs of the same plant type, between genotypes or cultivars of the same plant type, and within the same tissue or organ of the same plant type.

As carotenoids are known to attract animals, it is probable that humans were drawn in by their vivid hues as well throughout the domestication of numerous crops. The flow of metabolites into, through, and out of the biosynthesis, degradation, and sequestration pathways and cellular compartments involved in carotenoid accumulation is governed by multiple and complicated regulatory mechanisms. Variations in photomorphogenesis and plastid development are common processes (Llorente et al. 2017; Lu and Li 2008; Sun et al. 2018; Yuan et al. 2015). A better understanding of the molecular mechanisms behind carrot carotenoid accumulation is emerging.

Cultivated carrots have a higher percentage of carotenoids than wild carrots and white carrots, which are also known as Queen Anne's lace. Principal carotenoids include lutein, beta-carotene, and lycopene as the primary carotenoids found in primary colours, viz. yellow, orange, and red, respectively (Arscott and Tanumihardjo 2010). In addition to lutein, yellow and orange carrots may also contain modest levels of zeaxanthin and carotene, as well as phytoene, carotenes, and lycopene. Red carrots sometimes include a tiny amount of beta- and gamma-carotene, as well as lutein, in addition to lycopene (Arscott and Tanumihardjo 2010; Grassmann et al. 2007). Orange carotenoids are the only sources of provitamin A that have a carotene concentration of 13–40% of the plant's total carotenoids,

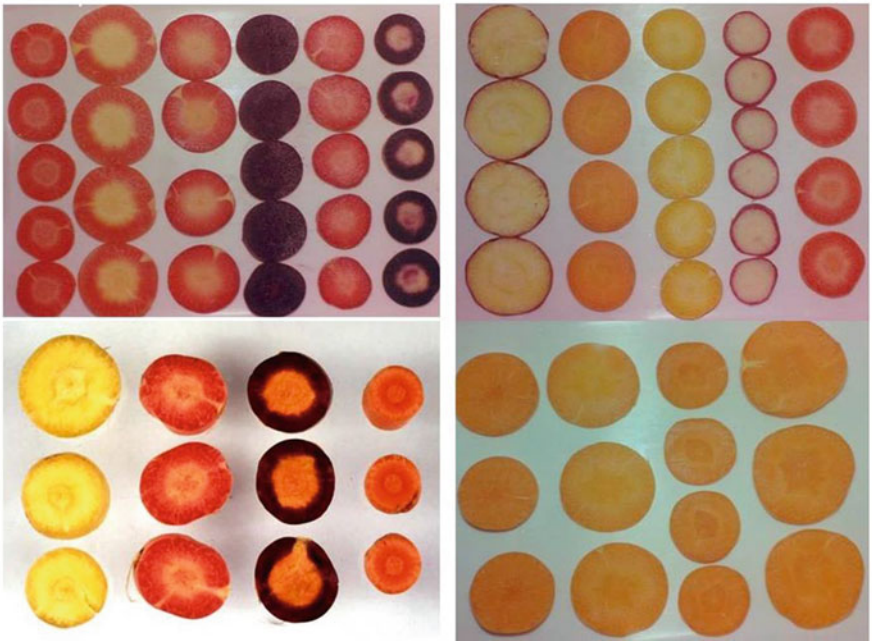

Fig. 22.2 Different colour expressions in carrot cross sections

whereas larger percentages are found in carotenoid roots with higher carotenoid total levels. Higher amounts of carotenoids may be found in carotenoid roots (Santos and Simon 2006; Simon and Wolff 1987). Carrots are thought to offer 67% of the daily recommended allowance of carotene in the typical American diet (Simon et al. 2009). For carotene plants with orange roots and those with yellow roots, the carotene-to-beta-carotene ratio is same in both types of plants; however, for the yellow-rooted plant, the ratio is higher (Arango et al. 2014; Perrin et al. 2016). Carotenoids in dark-orange cultivars may reach 500 parts per million (ppm) in fresh weight (Simon et al. 1989), which is linked to the growth of carotenoids and crystal formation in carotenoids in carrot-root chromoplasts (Baranska et al. 2006; Ben-Shaul and Klein 1965; Fuentes et al. 2012; Kim et al. 2010; Li et al. 2010; Maass et al. 2009). Colour expressions of different pigments in different parts of tropical carrot cross sections are depicted in Fig. 22.2.

The perusal of Table 22.4 shows the estimated carotenoids (Kalia and Singh 2016) in different coloured carrot varieties. Pusa Meghali had the highest amounts of total carotenoids and beta-carotene, followed by Pusa Rudhira, Pusa Kesar, Pusa Asita, and Pusa Kulfi while Pusa Kesar had the highest levels of lycopene, followed by Pusa Vrishti, Pusa Meghali, and Pusa Asita.

Different varieties of carrot, such as Pusa Kulfi, Pusa Asita, Pusa Rudhira, Pusa Meghali, and Pusa Vrishti, were nutritionally analysed (Kalia and Singh 2016). The perusal of Table 22.5 presents the highest total carotenoid content (5148 mg/100 g)

Table 22.4 Estimation of carotenoid content in carrot varieties

Carotenoids	Range	Pusa Kulfi	Pusa Meghali	Pusa Rudhira	Pusa Kesar	Pusa Vrishti	Pusa Asita
Total carotenoids (mg/100 g)	376.66–5147.95	376.66	4629.95	5147.95	5064.77	2538.98	435.99
Lutein (mg/100 g)	34.98–190.95	34.98	34.98	110.26	93.80	102.13	190.95
Lycopene (mg/100 g)	28.51–1913.68	BDL	32.69	386.10	1913.68	1334.6	28.51
Beta-carotene (mg/100 g)	25.56–3981.82	BDL	3981.82	830.90	783.53	749.29	25.56
α-Carotene (mg/100 g)	117.50–117.50	BDL	117.50	BDL	BDL	BDL	BDL

Table 22.5 Carotenoids and anthocyanins in different pigmented carrots

Carotenoids	Pusa Kulfi	Pusa Meghali	Pusa Rudhira	Pusa Kesar	Pusa Vrishti	Pusa Asita
Total carotenoids (mg/100 g)	377	4630	5148	5065	2539	436
Lutein (mg/100 g)	35	35	110	94	102	191
Lycopene (mg/100 g)	BDL	33	1386	914	1335	29
Beta-carotene (mg/100 g)	BDL	3982	831	784	749	26
Anthocyanin (mg/100 g)	–	–	–	–	–	339

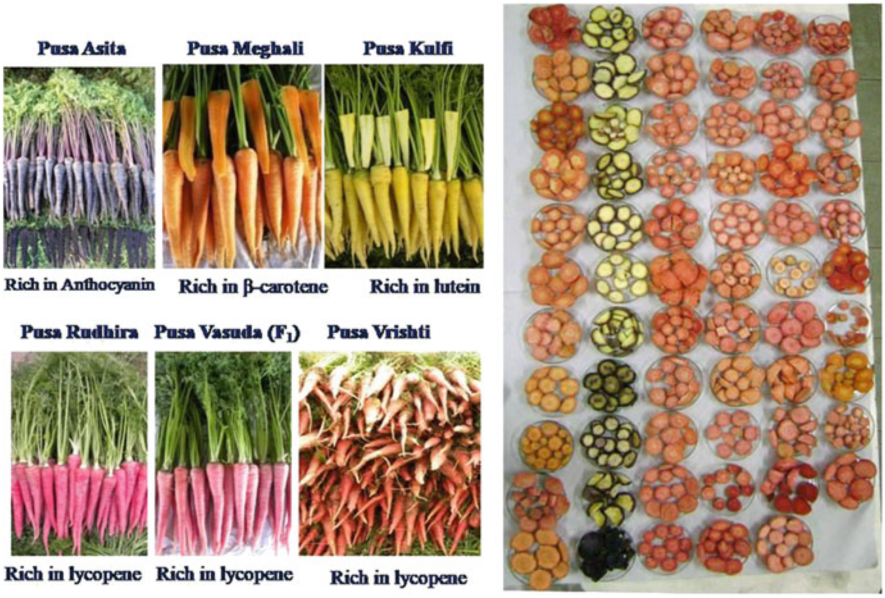

Fig. 22.3 Different colour expressions in periderm and core region

in Pusa Rudhira followed by Pusa Kesar (5065 mg/100 g), Pusa Meghali (4630 mg/100 g), Pusa Vrishti (2539 mg/100 g), Pusa Asita (436 mg/100 g), and Pusa Kulfi (377 mg/100 g). Different colour expressions in periderm and core region of tropical carrot are depicted in Fig. 22.3, and the multinutrient-rich CMS hybrids in Fig. 22.4. The nutrient-rich cross hybrids, however, are presented in Fig. 22.5.

22.1.3 Carrot Anthocyanins in Human Health

Many studies have employed purple carrots as a source of anthocyanins, which are powerful antioxidants. A study was conducted to determine the rate of anthocyanin

Fig. 22.4 Promising multinutrient-rich CMS hybrids

Fig. 22.5 Nutrient-rich promising cross combinations of carrot

recovery in blood plasma and urine after providing human subjects raw and microwaved purple carrots (Kurilich et al. 2005). It has been found that after additional cooking, NAA recoveries are 8–10 and 11–14 times larger than AA recoveries in plasma and urine samples, respectively. Given that Kurilich et al. (2005) analysed whole carrots, it was not possible to separate the plant matrix and anthocyanin chemical structure from the pigments' bioavailability in the study. With the purpose of avoiding matrix effects, an analogous feeding experiment with purple carrot juice was conducted, which resulted in fourfold better NAA recovery rates than those seen for AA (Charron et al. 2009). The higher bioavailability of NAA as compared to AA was most likely related to their chemical structure rather than interactions with the plant matrix, according to the researchers. It was discovered that NAA was four times more bioavailable than AA in carrot anthocyanins, according to these data (Charron et al. 2007).

The antioxidant capacity (AC) of purple and non-purple carrots and the link between AC and pigment concentration have all been investigated in this research project. When Sun et al. (2009) investigated the antioxidant activities of seven carrot cultivars with varying root colours, they discovered that purple carrots had the highest antioxidant activity, with values 3.6–28-fold higher than activities in other root colours, depending on the analytical method used (ABTS and DPPH) and the cultivars compared, respectively. The high antioxidant capacity of purple carrots was shown to be associated with their high quantity of phenolic compounds in general, and particularly anthocyanins, but not with their high content of carotenoids. Carotenoids contributed just a small percentage of the overall antioxidant capacity in purple carrots, accounting for less than 3% of the total antioxidant capacity (Sun et al. 2009). Additionally, Leja et al. (2013) evaluated AC in 35 carrot cultivars with various root colours, including two purple carrots, and discovered that purple carrots had the highest AC, which was associated with their level of phenolic compounds, which was ninefold higher than in carrots with other root colours. As an example of how AC can be measured, Algarra et al. (2014) tested three carrot cultivars from Spain, two of which were purple and one which was orange, and discovered that purple carrots had significantly greater AC than orange carrots and that AC in purple carrots was strongly related to total anthocyanin content.

It has been discovered that carrot anthocyanins are more potent antioxidants than traditional antioxidants such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and α-tocopherol (vitamin E), and it has been proposed that these pigments can prevent lipid auto-oxidation and peroxidation in biological systems, among other things (Narayan et al. 1999). Recent research conducted by Olejnik et al. (2016) discovered that purple carrot extract reduced DNA damage induced by oxidative stress in colon mucosa cells, indicating that anthocyanin-rich extracts from purple carrots may protect colonic cells from oxidative stress. Extracted purple carrots had strong antioxidant activity, which was compatible with the results of this study. Interestingly, a human intestine cell line that was tested positive for anthocyanins (AC) and had a lower level of inflammation markers than the control cell line suggests that anthocyanins from carrots may be useful in the reduction of intestinal inflammation responses (Zhang et al. 2016).

In addition to its antioxidant and anti-inflammatory properties, carrot anthocyanins have been proven to have antiproliferative actions against certain cancer types. A purple carrot extract was discovered to suppress the growth of two human cancer cell lines (HT-29 colorectal adenocarcinoma and HL-60 promyelocytic leukaemia) in a dose-dependent manner by Netzel et al. (2007). Similar findings were made by Jing et al. (2008), who observed that anthocyanin-rich extracts of carrots and other vegetables and fruits inhibit colon cancer cell proliferation, with carrot extracts having the second most effective antiproliferative effects among the anthocyanin-rich plants investigated. Using a variety of human cancer cell lines, including breast (MCF-7, SK-BR-3, and MDA-MB-231), colon (HT-29), and prostate (PC-3), as well as mouse neuroblastomas (neuro-2A), Sevimli-Gur et al. (2013) investigated the anticancer effects of purple carrot extracts on a variety of cancer cell lines and discovered dose-dependent cytotoxicity of carrot anthocyanins against all of them.

22.1.4 Dietary Fibre

Dietary fibre is a complex carbohydrate that is an indigestible and non-structural component of plants. They cannot be absorbed by the body and, thus, have no calorific value; however, the health benefits of eating a fibre-rich diet are numerous, including constipation prevention, blood sugar regulation, heart disease prevention, and reduction of high cholesterol and prevention of certain cancers. Depending on their solubility, fibres are classed as insoluble or soluble. Soluble fibres are non-cellulosic polysaccharides including pectin, gums, and mucilage, while insoluble fibres are mostly cell wall components like cellulose, hemicellulose, and lignin (Yoon et al. 2005). According to Lineback (1999), the cell wall of carrots is made up of pectin (galacturonans, rhamnogalacturonans, arabinans, galactans, and arabinogalactans-1), cellulose (1→4, β–D-glucan), lignin (*trans*-coniferyl alcohol, *trans*-sinapyl alcohol, and *trans*-p-coumaryl alcohol), and hemicellulose (xylans). Dietary fibres are abundant in carrots (Bao and Chang 1994), and these fibres play a significant role in human health (Anderson et al. 1994). Diets high in dietary fibres have been linked to the prevention, reduction, and treatment of disorders such as diverticular and coronary heart disease (Anderson et al. 1994; Gorinstein et al. 2001; Villanueva-Suarez et al. 2003).

According to Nawirska and Kwasniewska (2005), pectin (7.41%), hemicellulose (9.14%), cellulose (80.94%), and lignin (7.41%) make up the dietary fibre elements in fresh carrots on a dry weight basis (2.48%). Dietary fibres are attractive not just for their nutritional benefits, but also for their functional and technological properties, and they may be used as food ingredients as a result of these (Thebaudin et al. 1997; Schieber et al. 2001).

22.1.5 Phenolics

Phenolics, also known as polyphenols, have gotten a lot of interest lately because of their physiological effects, which include antioxidant, antimutagenic, and anticancer properties. It is a claimed competitor to fight free radicals, which are detrimental to

Table 22.6 Profiling of different phenolic compounds in carrot varieties

Phenolics (mg/100 g)	Range	Pusa Kulfi	Pusa Meghali	Pusa Rudhira	Pusa Kesar	Pusa Vrishti	Pusa Asita
Chlorogenic acid	0.04–1.70	0.19	0.17	0.06	0.05	0.04	1.70
Vanillic acid	0.01–0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ferulic acid	0.01–0.14	0.05	0.05	0.02	0.01	0.02	0.14
p-Coumaric acid	0.01–0.31	0.31	0.27	0.13	0.02	0.02	0.01

human health and food systems (Nagai et al. 2003). However, phenolic chemicals are completely non-nutritional, and their antioxidant capacity may be essential for human health (Hollman et al. 1996). Phenylalanine serves as the primary source of phenolics in plants (Dixon and Paiva 1995).

Carrots have phenolic compounds that are found throughout the roots but are particularly concentrated in the periderm tissue (Mercier et al. 1994). The hydroxycinnamic acids and *para*-hydroxybenzoic acids are two of the most important groups of phenolics (Babic et al. 1993). Furthermore, Zhang and Hamauzee (2004) investigated the phenolic compounds present in carrot, as well as their antioxidant capabilities and distribution, and discovered that it had a high concentration of hydroxycinnamic acids and derivatives. One of the most important hydroxycinnamic acids found in carrot tissues was chlorogenic acid, which accounted for 42.2–61.8% of the total phenolic compounds found in various carrot tissues. It was found that the phenolic content of various tissues in carrot dropped in the following order: peel, phloem, and xylem.

Although carrot peel accounted for just 11% of the weight of the carrot, it could supply 54.1% of the quantity of total phenolics, while the phloem tissue provided 39.5% and the xylem tissue provided only 6.4%. Antioxidant and radical scavenging capabilities declined in the same order as phenolic concentration. Phenolics seem to be essential in the antioxidant activities of carrots and other hydroxycinnamic derivatives, such as dicaffeoylquinic acids and chlorogenic acid. So, carrot peels handled as trash in the processing sector may be a good source of value-added uses.

According to Oviasogie et al. (2009), carrot has a total phenolic content of 26.59 ±1.70 μg/g. Karakaya et al. (2001) found that total phenols in violet carrot juice were 772,119 mg/L.

Kalia (2015) found the presence of various phenolics in different pigmented carrots, including chlorogenic acid (0.04–1.70), vanillic acid (0.01–0.01 mg/100 g), ferulic acid (0.01–014 mg/100 g), and *p*-coumaric acid (0.01–0.31 mg/100 g) (Table 22.6).

22.1.6 Organic Acids

Fruits and vegetables contain high levels of organic acids. Ascorbic acid (vitamin C) is the most often utilized acidic natural resource in the pharmaceutical industry due

Table 22.7 Profiling of different organic acids in the carrot varieties

Organic acids	Range (mg/100 g)	Pusa Kulfi	Pusa Meghali	Pusa Rudhira	Pusa Kesar	Pusa Vrishti	Pusa Asita
Malic acid	12.72–35.25	30.13	35.25	16.32	12.72	20.86	24.06
Citric acid	0.49–31.63	0.49	7.15	BDL	20.43	11.38	31.63
Succinic acid	20.02–114.58	21.44	20.02	21.89	50.49	27.26	114.5
Fumaric acid	1.23–6.98	2.21	6.98	1.34	4.66	4.04	1.23

to its significant antioxidant properties. A large variety of additional supplements, on the other hand, help to maintain and enhance normal biological activities. Benzoic acid has antimicrobial properties; hydroxycinnamic acid has anti-inflammatory properties; and gallic acid, among other things, has been shown to resist mutagenesis (Robles et al. 2019). Acetic acid and its salts have been found to boost iron absorption even more by the body. Consuming citric acid and its salts, as well as lactic and malic acids, among other things, are also beneficial.

These natural organic acids and sugars account for over 60% of the dry matter, soluble solid content, and flavour of fruits and vegetables (Zhao et al. 2016). Organic acids were shown to be responsible for the flavour and sweetness of carrot types. Kalia (2015) estimated different organic acids in carrot varieties and recorded the highest range of succinic acid (20.02–114.58 mg/100 g), which was observed to be the major cause of carrot flavour, followed by malic acid (12.72–35.25 mg/100 g), citric acid (0.49–31.63 mg/100 g), and fumaric acid (1.23–6.98 mg/100 g) (Table 22.7).

22.1.7 Minerals

The mineral content of a raw food product has an impact on its quality since it is an essential attribute. Carrot roots are also high in potassium, manganese, and phosphorus. These minerals are necessary for the body's overall health and function if it is to perform at its best. Mn is needed in trace levels in biosynthetic processes, whereas P is required by blood vessels and K is essential for healthy bone and muscle function. Other minerals, such as Na, Fe, and Mg, are essential for adequate muscle and nerve functions, in addition to calcium, which is required for the formation of bones, teeth, and blood cells (Ergun and Süslüoğlu 2018). Mineral contents estimated in different varieties of carrots by Kalia (2015) are presented in Table 22.8, and perusal of the table shows highest potassium content across varieties followed by sodium, phosphorus, and calcium, respectively.

Table 22.8 Mineral profiling of different carrot varieties

Minerals (mg/100 g)	Range	Pusa Kulfi	Pusa Meghali	Pusa Rudhira	Pusa Kesar	Pusa Vrishti	Pusa Asita
Fe	0.41–0.75	0.52	0.43	0.57	0.41	0.54	0.75
Zn	0.17–0.25	0.22	0.18	0.24	0.17	0.25	0.22
Cu	0.08–0.13	0.09	0.13	0.09	0.09	0.11	0.08
Mn	0.19–0.24	0.24	0.19	0.22	0.19	0.22	0.22
K	311.2–397.9	364.28	381.99	396.96	364.20	311.26	397.92
Mg	14.20–23.42	15.78	19.16	23.42	14.20	15.72	16.43
P	45.01–51.74	48.27	45.01	51.21	45.54	51.74	49.12
Na	51.80–73.57	51.80	65.49	71.93	55.64	60.07	73.57
Ca	24.62–39.32	29.54	35.48	39.32	24.62	38.30	32.99

22.1.8 Fatty Acids

Carrots are most widely consumed vegetables in the world for human nutrition. The majority of carrot seed oils are composed of unsaturated fatty acids, and it has been advised that these fatty acids should be used in lieu of saturated fatty acids owing to health concerns (Sabikhi and Sathish Kumar 2012). Women and men in their middle age and older years have a lower risk of cardiovascular disease (CVD), a lower LDL cholesterol level, and a lower risk of coronary heart disease (CHD) when unsaturated lipids are substituted for saturated lipids, according to widely recognized scientific evidence (Jacobsen et al. 2008; Kris-Etherton et al. 1999). The profiling of fatty acids carried out in fresh carrot roots of different varieties by Kalia (2015) is presented in Table 22.9.

22.2 Radish

The radish (*Raphanus sativus* L., $2n = 2x = 18$), a member of the Brassicaceae family, is a cool-season, fast-maturing, easy-to-grow annual or biennial herbaceous plant cultivated for its roots. Radish is primarily cultivated for its thicker meaty root, which is mostly used in salads. After boiling, its young leaves are also eaten. Although radish is cultivated and eaten all over the globe, it has minimal nutritional value. In order to know the nutritional quality of coloured radishes, researchers in the Division of Vegetable Science, ICAR-Indian Agricultural Research Institute, New Delhi, analysed roots of coloured radish varieties for essential nutrients, such as ascorbic acid, anthocyanin, and total carotenoids (Table 22.10). The perusal of the table showed highest total anthocyanin content (8.04 mg/100 g) in Pusa Jamuni, followed by Pusa Gulabi (4.41 mg/100 g). The ascorbic content (56.94 mg/100 g), however, was highest in Palam Hriday followed by Pusa Jamuni (39.25 mg/100 g). Pusa Gulabi had the highest concentration (15.6 mg/100 g) of total carotenoids. Nutra-rich radish varieties with colour expression in periderm and core region are presented in Fig. 22.6.

Table 22.9 Profiling of fatty acids in carrot varieties

Fatty acids	Range	Pusa Kulfi	Pusa Meghali	Pusa Rudhira	Pusa Kesar	Pusa Vrishti	Pusa Asita
C14: 0 myristic (%)	–	BDL	BDL	BDL	BDL	BDL	BDL
C16: 0 palmitic (%)	19.17–19.8	19.17	19.56	19.39	19.65	19.25	19.85
C18:0 stearic (%)	1.00–1.38	1.00	1.00	1.12	1.31	1.38	1.36
C20: 0 arachidic (%)	0.33–0.67	0.56	0.39	0.33	0.35	0.36	0.67
C22:0 behenic (%)	0.55–1.08	0.76	0.55	0.61	0.56	1.08	
C24: 0 lignoceric (%)	0.27–0.53	0.45	0.33	0.34	0.27	0.37	0.53
C18:1n9c oleic (%)	2.22–3.04	2.22	2.32	2.56	2.28	2.60	3.04
C18:2n6c linoleic (%)	66.5–68.4	68.4	68.4	68.19	67.99	68.42	66.53
C18:3n3 linolenic (%)	6.94–7.79	7.79	7.33	7.27	7.42	7.07	6.94
TSFA (%)	21.79–23.4	21.94	21.82	21.79	22.14	21.95	23.49
TMUFA (%)	2.22–3.04	2.22	2.32	2.56	2.28	2.60	3.04
TPUFA (%)	73.47–76.1	76.18	75.78	75.46	75.41	75.49	73.47

Table 22.10 Important nutritional status of Indian pigmented radish cultivars

Variety	Ascorbic acid (mg/100 g)	Anthocyanin (mg/100 g)	Total carotenoids (mg/100 g)
Pusa Gulabi	39.25	4.41	15.6
Pusa Jamuni	44.82	8.04	2.5
Palam Hriday	56.94	2.00	2.01

22.2.1 Root and Juices

Red radish, a strong source of anthocyanins, has 12 distinct forms of acylated anthocyanins (Otsuki et al. 2002). Six novel pelargonidin anthocyanin compounds have been identified and characterized. According to Wang et al. (2010), the antioxidant activity of pelargonidin, produced from the acylated anthocyanins found in red radish, has been demonstrated to be dose dependent in investigations on the radical scavenging capabilities of FRP and ABTS. Different varieties of Chinese red radishes have anthocyanin concentrations ranging from 63.77 to

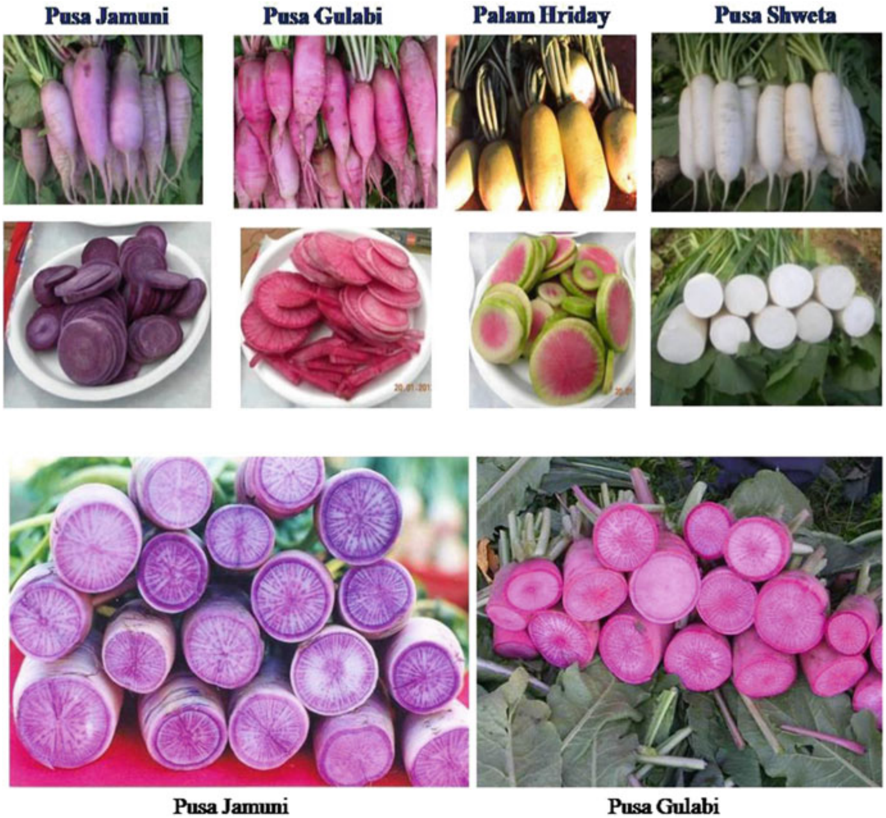

Fig. 22.6 Nutra-rich radish varieties with colour expression in periderm and core region

160.74 mg/100 g, making them, particularly, a rich source of the colour (Jing et al. 2012). Their results indicated that the average concentration of glucosides in Chinese red radish cultivars ranged from 59.69 to 163.91 mg/100 g.

Hanlon and Barnes (2011) found glucosinolates ranging from 17.1 to 100.0 mol/g and isothiocyanates from 3.9 to 7.6 mol/g in the adult taproots of eight distinct radish species. The most frequent glucosinolate chemicals in adult taproots were glucoiberin, glucoerucin, progoitrin, 4-hydroxyglucobrassicin, and 4-methoxyglucobrassicin. The antioxidant activity of the cultivars ranged from 18.5 to 53.9 mol AAE/g and 200 to 345 mol TE/g of FRAP and ORAC, respectively. The TPC in radish cultivars ranged from 2.0 to 4.2 g GAE/g, with the exception of Nero Tondo, Miyashige, and Ping Pong (all of which have low anthocyanin concentration) (Hanlon and Barnes 2011).

According to Beevi et al. (2009), the isothiocyanate content of the radish root ranges from 0.42 to 1.18 mg/g, with chloroform extract having the greatest concentration and water extract having the lowest. In terms of overall isothiocyanate concentration, the hexane fraction of the roots had much larger concentration

(3.81 mg/g) than the acetone fraction (1.82 mg/g). The isothiocyanate concentrations in the hexane and acetone fractions differed, with 4-(methylthio)-3-butenyl being the most abundant in the hexane fraction and phenyl isothiocyanate being the most abundant in the acetone fraction.

Sangthong et al. (2017) found 6 distinct glucosinolates, 13 isothiocyanates, 5 indoles, 4 flavonoids, 2 each of alkaloids and thiocyanates, and 1 each of oxazolidine and dialkyl disulphide compounds in radish cultivars. Caudatus Alef. isoalliin and butyl 1-(methylthio) propyl disulphide were the first two chemicals discovered in radish. Salah-Abbès et al. (2009) found 38.98 mol/100 mg isothiocyanate content in Tunisian radish. According to Koley et al. (2020), root periderm has a higher antioxidant capacity than the xylem. The antioxidant activity of the root's periderm was 20.4, 28.1, 13.04, and 17.8 mol-TE/g, whereas in xylem it was 3.0, 7.8, and 2.24 mol-TE/g. Further, the root periderm was reported to contain 78% acylate anthocyanins, 2% total non-acylate anthocyanins, 1% overall phenolic acids, 16% total acylated flavonols, 2% total non-acylated flavonols, and 1% total flavanones. The root xylem contains 90% of the total acylated anthocyanins, 2% of the total polyphenolic acids, and 10% of the total flavonols.

22.2.2 Leaves

Radish leaves are rich sources of antioxidants because of high concentration of bioactive compounds in them. Antioxidant activity of red radish leaves was found to be 1.76, 3.39, and 39.48 mmol TE/100 g dm, as determined by DPPH, FRAP, and ORAC assays, respectively (Goyeneche et al. 2015). The antioxidant potential of leaves is 3.6 times higher than that of roots, as determined by the ORAC method. TPC (695.07 mg GAE/100 g) levels in red radish leaves were found to be two times higher than in roots. Red radish leaves had a TFC of 1042.73 mg QE/100 g, which is four times higher than that of TFC in the roots (Goyeneche et al. 2015). Phenolics and flavonoids have potent radical scavenging properties, which improved the radish leaf extracts' antioxidant activity (Beevi et al. 2012). Epicatechin, tyrosol, and *trans*-sinapic acids are the most abundant phenols in the free form of phenolic acids found in radish leaves, while vanillic, coumaric, and *trans*-ferulic acids are the most prevalent phenols in the bound form. Epicatechin acid and *trans*-sinapic acid are the most abundant phenols in the bound form, while coumaric acid and caffeic acid are the most abundant phenols. Free phenolics made up 55% of the total phenolic compounds, whereas bound phenolics made up the rest of the total phenolic compounds. Tocopherols, flavanols, and carotenoids found in radish leaves contribute to their high antioxidant capacity (Goyeneche et al. 2015). Photosynthesis occurs in abundance in plants with high concentrations of chlorophyll and carotenoids. Chlorophyll (a, b) and beta-carotene are found in radish leaves at a concentration of 0.53 mg/100 g, 0.18 mg/100 g, and 0.46 mg/100 g, respectively. A foliar application of plant extracts at a dosage of 3% raised the total carotenoid and total chlorophyll content significantly. When the concentration of plant extracts was raised by foliar spray, the amount of plant extracts in radish leaves decreased.

22.2.3 Flavonoids and Non-flavonoids

Anthocyanins were the most abundant subclass of flavonoids, accounting for 208 of them in radish. Anthocyanins have been identified in nature as anthocyanidin glycosides and acylated anthocyanins. The most prevalent anthocyanidins found in fruits and vegetables are cyanidin (50%), delphinidin (12%), pelargonidin (12%), peonidin (12%), petunidin (7%), and malvidin (7%) (Khoo et al. 2017). Apart from anthocyanins, the most often reported flavonoid was catechin, which was found in leaves, stems, and skin (Beevi et al. 2010; Papetti et al. 2014). Phytochemicals, such as phenolic acids, hydroxycinnamates, stilbenes, and tannins, are non-flavonoid polyphenols. With a total of 51 chemicals discovered throughout the whole radish plant, the data on the amounts of 22 phytochemicals examined in 16 studies were available for 22 of the 51 reported non-flavonoid polyphenols. The polyphenols 4-ethyl-2-methoxyphenol, 4-vinyl-2-methoxyphenol, caffeic acid, *p*-coumaric acid, phenol, sinapic acid, and vanillic acid have been discovered in several studies. Except for caffeic acid, these compounds are among the most concentrated phenols in *Raphanus sativus*, with the highest concentration of 4-vinyl-2-methoxyphenol (12.4 mg/100 g FW, white radish) and vanillic acid (413 mg/100 g DW, radish variety not given). Notably, leaves have the highest amounts of these chemicals.

22.2.4 Total Phenolic Content (TPC)

Shehata et al. (2014) reported a value of 29 mg/100 g FW of TPC in red radish leaves, while Pushkala et al. (2013) reported a value of 6.1 mg/100 g FW TPC in the roots of an unknown variety. Among the studies that reported the total gallic acid equivalent (GAE) content in mg/100 g dry weight (Ashraf et al. 2018; Tsouvaltzis and Brecht 2014), the greatest concentration was observed in the roots (14.6 mg GAE/100 g FW) of an unidentified variety. Three publications (Goyeneche et al. 2015; Gurav et al. 2014; Hanlon and Barnes 2011) reported their findings in mg GAE/100 g DW; in this instance, the values for roots varied from 422 mg GAE/100 g DW to 0.2 mg GAE/100 g DW (white radish). Goyeneche et al. (2015) reported that leaves contained 695 mg GAE per 100 g DW. Finally, Hanlon and Barnes (2011) obtained an average of 1.97 mg GAE/100 g DW of sprouts from various cultivars.

22.2.5 Terpenes and Derivatives

Carotenoids, terpenes, terpenoids, triterpenoids, and steroids are all members of this class of phytochemicals. In terms of quantitative analysis, squalene in marushka radish roots comes in top (40.9 mg/100 g FW), followed by two carotenoids in second and third places (beta-carotene and lutein/zeaxanthin in opal cultivar sprouts with 6.3 mg/100 g FW and 5.5 mg/100 g FW, respectively). In terms of other concentration measurement units in this category, Chen et al. (2017) reported carvone as the highest concentrated phytochemical (13.49 mg/L) in red radish.

22.2.6 Glucosinolates and Breakdown Products

Radishes are distinctive among cruciferous vegetables in that they contain glucosinolates, which are precursors to isothiocyanates. Glucosinolates are anions comprised of thiohydroximates with an S-linked β-D-glucopyranosyl residue and an O-linked sulphate residue, as well as an amino acid-derived, changeable side chain; sometimes, additional substituents are added to the side chain or glucosyl moiety's O, S, or N atoms (Agerbirk and Olsen 2012). Glucosinolates are believed to be stored in plant cells' vacuoles (Andreasson and Jørgensen 2003). Glucosinolates interact with myrosinase, an enzyme that catalyses the fast breakdown of isothiocyanates, thiocyanates, nitriles, or epithionitriles when the plant is physically damaged (Wittstock et al. 2016). The pH of the solution and the presence of specifier proteins (NSP, nitrile-specifier protein, ESP, epithiospecifier protein, TFP, thiocyanate-forming protein) direct the production of one of these end products (Kuchernig et al. 2012; O'Hare et al. 2007). Numerous studies quantified and qualitatively described 34 glucosinolates and breakdown products found in all radish sections.

With regard to glucosinolates specifically, the most commonly reported substance was 4-methylthiobut-3-enylglucosinolate (glucoraphasatin) in publications analysing this area. Additionally, it had the greatest concentration when data were given in mol/g FW (17.1 mol/g FW) and mol/g DW (108.3 mol/g DW, white variety). Both of the above-mentioned values were discovered in radish sprouts. Finally, Baenas et al. (2014) compared the concentrations of (*R*)-4-methylsulphinylbut-3-enylglucosinolate (glucoraphenin) in seeds and sprouts of two radish varieties in mg/100 g FW, finding that (*R*)-4-methylsulphinylbut-3-enylglucosinolate (glucoraphenin) was the most concentrated glucosinolate. Baenas et al. (2014) found 1293 mg/100 g FW in China rose radish seeds, whereas Jing et al. (2012) looked at it in mg/100 g DW in red radish roots (Xin Ling Mei Cv.), finding 163.1 mg/100 g DW as the highest level. Yuan et al. (2010) recorded the highest TGC in mol/g FW (17.55 mol/g FW) in sprouts of an unknown variety, whereas Hanlon and Barnes (2011) found 133.9 mol/g DW in white Miyashige radish sprouts; this quantity is noteworthy when compared to 21 mol/g DW in the same cultivar roots.

Isothiocyanates and thiocyanates were discovered as breakdown products of glucosinolates in the studies. The phytochemicals were studied in radish roots, leaves, and sprouts, and 4-(methylthio)-3-butenyl isothiocyanate (raphasatin) was described in four separate publications, making it the most commonly reported intermediate product. In terms of concentrations, when the data was expressed as a percentage, 4-(methylthio) butyl isothiocyanate (erucin) had the highest concentration in white radish roots, at 25.7%. The only compound measured in mg/100 g DW was 4-(methylsulphinyl) butyl isothiocyanate (sulphoraphane) (Im et al. 2010); its highest concentration in roots was found in white radish (5.26 mg/100 g DW), but it was also found in leaves, with the highest concentration in red radish (4.21 mg/100 g DW). Sun and Chen (2019), Matera et al. (2012), Hanlon and Barnes (2011), and Matera et al. (2012) reported their results in mol/g DW, and Matera et al. found the highest concentration of TIC in sango cultivar sprouts at 77.8 mol/g DW, whereas Hanlon and Barnes found the highest concentration in red radish sprouts at 77.6 mol/g DW. These values are much lower than Sun and Chen's findings in red radish (1.43 mol/g DW).

22.3 Turnip

Turnip is one of the most significant leaf and root crops in the world, and it is grown all over the globe. When grown for its tasty roots and leaves (greens), it is harvested during the vegetative phase; nevertheless, the turnip tops, which are fructiferous stems with flower buds and surrounding leaves, which are eaten before the flowers bloom and when still green, are also popular. In spite of the fact that young turnip roots are frequently eaten raw in salads, the greens and tops of turnip are typically served cooked or steamed. To distinguish them from other Brassica vegetables such as broccoli, cabbage, and cauliflower, the turnip leaves have a harsh flavour. Turnip root is regarded to be less helpful to human health than its tops and leaves, owing to the presence of just a minimal quantity of phenolic compounds and a negligible antioxidant activity. The important varieties of turnip in India are presented in Fig. 22.7.

22.3.1 Nutritional Profile

Turnips have a low fat and calorie content, but are a good source of minerals, vitamins, and bioactive compounds, and have a high dry matter digestibility, all of which are important for a healthy lifestyle. The complex chemical makeup of turnip accounts for its high nutritive value. Apart from being an important vegetable, turnips contain a significant amount of phytochemicals, aromatic compounds, organic acids, essential oils, and other non-nutritive compounds that have health benefits such as antibacterial and anti-carcinogenic properties, as well as increasing

Fig. 22.7 Popular varieties of turnip grown in India

the immune system in the human body (Haliloglu et al. 2012). The antioxidant properties of non-nutritive substances found in turnips (polyphenols, flavonoids, isoflavones, and glucosinolates) help the body scavenge damaging free radicals, which may protect tissues from oxidative damage, cancer prevention, inflammation, and immune system enhancement (Silva et al. 2004). The strong antioxidant activity of *Brassica* species exhibits a protective impact on the oxidation of lipoproteins; it is vital to consume natural antioxidants from turnips for a healthy life (Kural et al. 2011). The turnip greens have a high concentration of critical elements that are absent in turnip roots and stems. Turmeric greens are high in antioxidants, such as carotenoids, xanthines, lutein, and vitamins A and C as well as a good source of vitamin K. Turmeric greens are also a good source of vitamin K. According to Cartea et al. (2012), the turnip's top greens are a rich source of the vitamin B complex, which includes riboflavin, pantothenic acid, and thiamine, among other nutrients. Fresh turnip greens also contain significant amounts of calcium, iron, copper, and manganese, all of which are essential mineral sources.

22.3.2 Antioxidant Activity

Free radical oxidative damage to tissues, an imbalanced diet, and other connected variables are linked to more than 30% of degenerative illnesses, including malignancies (Czapski 2009). Natural antioxidants found in foods (fruits and vegetables) have been shown in epidemiological studies to promote health and reduce cancer and other degenerative disease death rates. Because of their high dry matter digestibility and vital secondary metabolites, such as glucosinolates, isothiocyanates, flavonoids, isoflavones, polyphenols, carotenes, anthocyanins, zeaxanthins, folacin, selenium, lutein, and ascorbic acid, brassicaceous plants (*Brassica rapa*) are consumed in large amounts. By reducing the detrimental effects of free radicals, these secondary metabolites have an important preventive function against numerous kinds of malignancies and cardiovascular and other degenerative diseases caused by various sources (Haliloglu et al. 2012). Because of their anti-carcinogenic qualities, these metabolites have a positive impact on human health (Zhao et al. 2007; Cartea and Rodriguez 2008). The antioxidant activity and chemoprotective properties of turnips are due to the presence of phytochemicals (glucosinolates, polyphenols, isothiocyanates, flavonoids, carotenes, terpenes, aldehydes, esters, and other substances) (Pierre et al. 2011).

22.3.3 Phenolic Compounds and Organic Acids

According to the literature, a diet high in fruits and vegetables may help to prevent the onset of different illnesses, such as diabetes, cancer, cardiovascular disease, and other diseases (Christensen 2009). Organosulphur compounds, glucosinolates, and other secondary metabolites, such as carotenoids, phytosterols, and other phytonutrients, are some of the chemicals linked with the health-promoting benefits of vegetables (Ferreres et al. 2005). Based on the findings of Witman (2011), the focus has recently shifted to other potentially health-promoting compounds found in a variety of natural vegetable products, which may help to explain the health benefits of vegetables such as carrots and other related vegetables, which contain polyacetylenes of the falcarinol type, which have a wide range of biological activities, including anti-inflammatory and anticancer effects.

Dietary flavonoid chemicals are mostly obtained from vegetables, which are their abundant source (Haytowitz et al. 2002). Heimler et al. (2013) used high-performance liquid chromatography (HPLC) to analyse different flavonoid and hydroxycinnamic derivatives found in aqueous turnip extracts. Flavonoids have the potential to lower the risk of cardiovascular disease, cancer, and inflammatory diseases in humans. These are sinapic, ferulic and caffeic acids, 1, 20-disinapoyl-2-feruloyl gentiobiose, kaempferol 3-*O*-sophoroside-7-*O*-sophoroside, kaempferol 3,7-*O*-diglucoside, isorhamnetin 3,7-*O*-diglucoside, and kaempferol 3-*O*-(feruloyl/caffeoyl)-sophoroside-O-7-glucoside. The phenolic compounds present in the turnip's stem, leaves, and flower buds include kaempferol 3-O-sophoroside-7-*O*-glucoside, 3-*p*-coumaroylquinic acid, 1,2-disinapoylgentiobiose, isorhamnetin 3-*O*-glucoside, and kaempferol 3-*O*-glucoside. The turnip is also rich in vitamin C. Similarly, on the examination of turnip roots, sinapic and ferulic acids, as well as their by-products, were found to be present in trace quantities. Isorhamnetin 3-*O*-glucoside, 1,20-disinapoyl-2-feruloyl gentiobiose, kaempferol 3,7-*O*-diglucoside, kaempferol 3-*O*-sophoroside, 1,2-disinapoyl gentiobiose, and kaempferol 3-*O*-glucoside and isorhamnetin 3, 7-O-diglucoside were the compounds in common when compared with the results obtained for the *B. rapa* variety (Kumar and Andy 2012; Romani et al. 2006a). There were 10–19 g/kg and 8–13 g/kg of phenolic compounds identified in different turnip extracts, with the flower buds and leaves and stems having 10–19 g/kg and 8–13 g/kg on a dry weight basis, respectively (Ludwig et al. 2011). Similarly characterized compounds were found in the leaves and stems, with 3-*O*-sophoroside-7-*O*-glucoside, 3-*O*-(feruloyl/caffeoyl)-3-*O*-glucoside, isorhamnetin 3,7-*O*-diglucoside, and 3-*O*-glucoside present in greater amounts, and others were 3-*p*-coumaroylquinic acid, 1,2-disinapoylgentiobiose, and 1,20-disinapoyl-2-feruloyl gentiobiose (Rafatullah et al. 2016). In addition, sinapic acid and kaempferol 3-*O*-glucoside were discovered in higher concentrations in the turnip flower buds, while caffeic acid and kaempferol 3-*O*-sophoroside-7-*O*-sophoroside were detected in lower concentrations in the flower buds. Turnip flower buds, on the other hand, had considerably lower levels of the caffeic acid-kaempferol 3-*O*-sophoroside-7-*O*-sophoroside combination and significantly higher amounts of sinapic acid, 1,20-disinapoyl-2-feruloyl gentiobiose, and kaempferol 3-*O*-glucoside than the leaves and stems (Christensen 2009). Furthermore, despite the fact that there were quantitative variations in the organic acid contents of various extracts from the same plant material, ketoglutaric, shikimic, citric, aconitic, malic, and fumaric acids were detected in almost all of the turnip sections (Francisco et al. 2011). The organic acid content of the leaves, stems, and flower buds, on the other hand, was considerably greater (36–51 g/kg) than the organic acid level of the roots (Fernandes et al. 2007). It was discovered that the stem, roots, and leaves had a tiny quantity of aconitic acid and that shikimic acid was a minor component in the flower buds (Daryoush et al. 2011). In a similar vein, ketoglutaric and citric acid were found in greater quantities in the flower buds, whereas malic acid was found in high proportions in all of the turnip's edible parts. Among the vegetables tested, turnip root had the highest content of malic acid (81%), followed by the leaves and stems (60% and 65%), and the flower buds (44%). The amount of aconitic acid in the flower buds (14%) was greater than in the roots, which was comparatively lower (2%). Various acids such as shikimic, citric, aconitic, malic, and fumaric acids have been shown to have antibacterial action against gram-negative bacteria in the literature (Sousa et al. 2008). However, shikimic acid is often utilized as a starting material in the commercial production of the antiviral medication oseltamivir (which is effective against the H5N1 influenza virus and may be used to treat and prevent all known strains of the influenza virus) (Bradley 2005; Bochkov et al. 2012). In addition, a Chinese research team has produced triacetyl shikimic acid, a shikimic acid derivative with anticoagulant and antithrombotic properties. This compound was discovered by accident (Huang et al. 2002). In another research, citric acid demonstrated antioxidant and anti-inflammatory benefits in brain tissue after being given orally at 1–2 g/kg for 24 h. A similar positive liver-protective effect was seen when citric acid was given in the same dosage range as the other compounds (Abdel-Salam et al. 2014).

22.3.4 Bioactive Compounds

The enzyme found in turnip contributes to five distinct metabolic pathways, which include nitrogen, methionine, cysteine, sulphate, and selenoamino acid metabolism, as well as sulphur metabolism (Milkowski et al. 2004). The dietary phytonutrients contained in turnips have the ability to lower the risk of developing cardiovascular disease and cancer in the future. Research on chemoprotection approaches has concentrated on the biological activity of plant-based flavonoids, isoflavones, polyphenols, terpenes, and glucosinolates, as shown by Agati and Tattini (2010) in their review of the literature. According to Batista et al. (2011), the phenolic chemicals found in turnips may have the ability to serve as a natural pesticide, aiding in the improvement of the plant's resistance to various parasites and diseases. The amount of phenolic compounds present in the turnip may vary depending on the degree of maturity, the cultivar, and the time of germination (Ayaz et al. 2008). Dergal et al. (2002) have found that tannins may interfere with iron bioavailability and protein absorption by creating insoluble complexes with the protein and minerals, respectively (Gemede and Ratta 2014; Delimont et al. 2017). Functional and nutraceutical foods have risen to the top of the priority list in the fields of behavioural nutrition and diets (Batista et al. 2011). Recent increases in the consumption of vegetables and fruits in the diet of the general public have not only substantially enhanced consumer health, but also reduced the likelihood of developing chronic diseases. Foods derived from plants, in addition to providing basic nourishment, also include significant amounts of bioactive chemicals, which are beneficial to the health of the consumer (Dillard and German 2000). Turnips contain 14 distinct phenolic compounds in their edible part, which includes the stems, roots, leaves, and flower buds. Turnip has high concentrations of isorhamnetin 3,7-*O*-diglucoside, 3-*O*-sophoroside-7-*O*-glucoside, isorhamnetin 3-*O*-glucoside, and 3-*O*-(feruloyl/caffeoyl)-sophoroside-7-*O*-glucoside, as well as malic acid, which is the primary organic acid found in higher concentrations in the turnip. In addition to this, the turnip blossom buds have a considerable amount of antioxidant capability to them. The turnip's upper greens and roots contain a trace amount of oxalic acid (0.21 g per 100 g), which may result in oxalate stones in the urinary system if consumed in large quantities. As a result, enough water consumption is recommended in individuals who are at increased risk for kidney stones in order to maintain a regular urine output (Lin and Harnly 2010). The organoleptic qualities of vegetables and fruits may be enhanced by bioactive non-nutritive substances that are present in high concentrations (Francisco et al. 2009). According to Romani et al. (2006b), the organic and phenolic acids found in the *Brassica* genus, as well as their by-products, have been extensively studied throughout the years. Recently, there has been an increase in interest in the synthesis and delivery of therapeutic proteins by researchers. Both alpha- and beta-interferons, which are therapeutic proteins produced under certain circumstances, such as fermentation, may be substantially essential in the treatment of different illnesses such as cancer, heart disease, hepatitis A and B, anaemia, and diabetes, according to this viewpoint (Auger et al. 2010). These proteins are generated via microbial fermentation in cell cultures, in transgenic turnip roots, and in a variety of different products, among other methods. A large number of therapeutic proteins are generated primarily via parenteral methods. Diverse new methods for the production of therapeutic proteins have been investigated and developed in order to achieve maximum effectiveness with the least amount of danger (Muheem et al. 2016).

Herbal treatments have been more popular in recent years, while conventional therapies have become less popular (Rivera et al. 2013; De-Smet 2002). This increasing demand is attributable to the wide range of health advantages that these herbal treatments provide in the treatment of a wide range of diseases. The turnip is used as a traditional medicine in Arabia and Unan for a variety of ailments including constipation, chronic gastritis, cholecystolithiasis, liver disorders, and cancer (Pithford 2002; Hartwell 1971). A research was conducted to investigate the antihepatitic and antioxidative effects of turnip in rats that had been exposed to CCl4 (carbon tetrachloride)-induced liver injury (Bhinu et al. 2009). When CCl4 was administered to the rats, it was shown that their nonprotein-sulfhydryl activity decreased significantly when compared to the control group. With the maximum dosage (16 mL/kg), treatment with turnip juice was able to reverse the decline in these activities caused by the CCl4 exposure, with the activity levels returning to normal (Nair et al. 2000). Also in rats, the administration of an aqueous extract of *Brassica rapa* chinensis (250 or 500 mg/kg) reduced the amount of free radicals produced by tert-butyl hydroperoxide (t-BHP). The treatment with the aqueous extract of *Brassica rap chinensis* substantially reduced the oxidative stress caused by t-BHP in the hepatic tissues, as indicated by a considerable improvement in the antioxidant status and a significant reduction in the levels of lipid peroxide in the liver tissues. In this study, the findings were dose dependant, with a 500 mg/kg bw dosage *of Brassica rapa chinensis* aqueous extract showing the highest promise in reducing the toxic effects of t-BHP (tetrahydrofurfuryl chloride) (Kalava and Mayilsamy 2014; Al-Snafi 2015). Several *Brassica* species, including turnip, have been studied in the past for their anti-carcinogenic properties (Kristal 2002). As a result, *Brassica* vegetables are consumed for health benefits, which are associated with their antioxidant activity (Plumb et al. 1996), and the most potent antioxidants found in turnips and related vegetables are likely to be phenolic compounds, such as flavonoids, which are present in high concentrations. As a result, these polyphenols scavenge free radicals and disrupt the propagation chain (the second defence line) or block the start of the chain (the first defence line) (Shi et al. 2009; Robards et al. 1999). Due to the discovery of many bioactive substances such as flavonoids, phenylpropanoid derivatives, indole alkaloids, and sterol glucosides in the turnip, the turnip is now gaining even more attention for its anti-diabetic properties (Romani et al. 2006a). Diabetic patients benefit from flavonoids in a variety of ways, and various flavonoids have varied benefits (Podsedek et al. 2006). The antioxidant isorhamnetin, for example, has a critical function in reducing the action of aldose reductase, which is directly linked to diabetes problems. Furthermore, kaempferol plays an essential function in the prevention of diabetes by boosting glucose absorption in rat muscles and decreasing blood glucose levels (Rajesh and Latha 2014). Furthermore, owing to the presence of streptozotocin, quercetin reduces the blood glucose level and increases the plasma insulin level in diabetic rats (Srinivasan et al. 2018). The findings of a comparable research investigated the possibility that the ethanolic extract of turnip roots had an anti-diabetic impact in patients with type 2 diabetes, by improving glucose and lipid metabolism (Sen et al. 1993). Turnip's antioxidant properties are due to the presence of flavonoids and hydroxycinnamic acid derivatives, which are abundant in the plant (Syed et al. 2004). Turnip root extracts have also been shown to have a protective effect against the first hepatic damage caused by alloxan-induced diabetic rats, according to the same research findings. The ethanolic extract of turnip has also been reported in the literature to lower serum biomarker levels of hepatic injury (Nouairi et al. 2008), and it would appear that the ethanolic extract has a protective effect on the early diabetic hepatopathy in rats with experimentally induced diabetes (Nouairi et al. 2008).

22.3.5 Volatiles

When it comes to flavour and aroma, volatile compounds in plants play an essential role. *Brassica* plants contain a varied spectrum of natural combinations with well-known bioactivities that enhance human health. Herbivore-initiated plant volatiles (HIPVs) and direct (found essentially in the plant) forms are also accessible. Herbivorous assault on plants leads to the development of an unstable chemical that may be transferred among nearby plants as a sign of self-assurance. Carbonyls, nitrogen, and sulphur make up the majority of turnip's bioactive volatile organic molecules. The metabolic activities that occur during the maturation, harvest, and storage of fruits and vegetables produce these volatiles (Heil 2008). In addition to protecting against diseases like diabetes and cardiovascular disease, these bioactive volatiles may serve as a barrier against microbial and herbivorous invasions.

22.3.6 Flavonoids

Flavonoid chemicals, which are found in the form of glycosides in *Brassica* species, are secondary metabolites. When compared to other high-water-content vegetables, the *Brassica* genus has a higher concentration of flavonoids and other bioactive substances that are beneficial to human health. The most well-known and varied categories of polyphenols in the *Brassica* genus are flavonoids and hydroxycinnamic acids. The proportion of phenolic compounds (flavonoids) in various regions of the turnip ranges from 57.71 to 38.99 mol/g (Francisco et al. 2009). These chemicals have free radical quenching properties because they prevent cancer-causing molecules from being biologically activated and increase the detoxification of reactive oxygen species (ROS) (Morales-Lopez et al. 2017). A flavonoid-rich diet is essential for a healthy lifestyle since it protects against cardiovascular disease, coronary artery disease, pigmentation, and other degenerative illnesses caused by an imbalance in individual’s antioxidant and other status (Crozier et al. 2006). Simple molecules, low-molecular-weight compounds, single fragrant cyclic compounds, massive and complicated tannins, and derivatized polyphenols are the scientific classifications for phenolic compounds. They are organized by the quantity and structure of carbon molecules in flavonoids like flavonols, flavones, flavan-3-ols, anthocyanidins, flavanones, isoflavones, and others, as well as non-flavonoids like phenolic acids, hydroxycinnamates, and stilbenes. The epidermis of leaves and fruit has a high concentration of them. The most well-known aglycones from this plant are kaempferol, quercetin, and isorhamnetin, which are among the 35 flavonoids found.

22.3.7 Glucosinolates and Isothiocyanates

Glucosinolates and related compounds found in turnip have a wide range of bioactivities and are believed to be beneficial to human health (Rosa et al. 1997). *Brassica* crops contain 1500–2000 g/g of the phytochemical glucosinolate, according to Ehlers et al. (2015). The glucosinolate structure consists of a β-D-thioglucose group, a sulphonated oxime (R-C_{14}NOH) group, and a variable side chain derived from amino acids. Side chain (R) may be aliphatic (alkyl, alkenyl, hydroxyalkenyl), aromatic (benzyl), or heterocyclic (indolyl) in structure. Changes in the chain’s structure lead to the creation of several different glucosinolates (Holst and Williamson 2004).

Anticancer and antimutagenic properties have been suggested for the phytochemicals generated by the metabolism of glucosinolates, known as isothiocyanates (Cartea and Rodriguez 2008). Only a few isothiocyanates, such as those found in *Brassica* crops, are widely consumed and present in a limited number of foods. Antibacterial, antiviral, and anticancer properties of isothiocyanates include their ability to decrease systemic oxidative stress, to induce apoptosis, to impede cell cycle progression, and to prevent angiogenesis (Fowke et al. 2011). The chemopreventive activity of isothiocyanates has been related to two main mechanisms. Using an isothiocyanate to inactivate the stage I enzyme cytochrome P450s, similar to how stage II enzymes are induced, was the first approach discovered. Apoptosis, which eliminates genetically defective cells, and the halting of the cell cycle are two more methods (Kalpana Deepa Priya et al. 2013).

Sulphur compounds and flavonoids like glucosinolates and indolides and isothiocyanates are among the phytochemicals found in turnips that may protect the body from a number of degenerative diseases. They are the most economically important and commonly grown crops in temperate climates across the globe, and their popularity has gradually increased over the last several decades. Turnips have a significant nutritional and dietetic value because of their high phytochemical content. Both the root and the greens of turnips are well known as food sources, and they are regarded as essential to a balanced diet since they include vitamins, minerals, and dietary fibre. Turnip fodder has been shown to be a viable alternative to stockpiled forage or commercial feeds throughout the fall and early winter months. *Brassica* fodder, which has a high nutritional value, must be considered while balancing the diets of ruminant animals.

22.4 Garden Beet

Garden beet, a member of the Chenopodiaceae family, is grown for its fleshy root, which is a commercial product that consists of the hypocotyl and crown. Garden beetroots may be eaten cold, typically in a salad drizzled with oil and vinegar, in addition to being consumed boiling as a cooked vegetable. A large portion of commercial production is made up of boiled and sterile beets or pickles. Young leaves are used as herbs in Indonesian and Japanese cuisine. Garden beet juice is a popular health food with anticancer and anti-inflammatory properties. Betanins, which are present in the roots, are utilized in the food industry as red food colourants, for example, to improve the colour of red tomato paste.

The value of red beet remains high due to its high concentration of red pigments, namely betalains. This pigment has outstanding colour values and may be used in both culinary and medicinal applications. Only the red beet and the prickly pear (*Opuntia ficus-indica*) have been allowed for use in culinary and medicinal applications for betalains, which may be found in a variety of plants (Jackman and Smith 1996; Mabry et al. 1963). The United States' Food and Drug Administration has allowed the use of beet extract to colour food (FDA). The only betalain-producing crop that has attained this level of production and betanin concentration (40–200 mg betanin/100 g fresh 0.4–20 mg/g dried beetroot) is red sugar beet. It is a feat that no other betalain-producing crop has ever accomplished. Betalains are found in plants of the Caryophyllales order, which includes red beet. Didiereaceae, a small family from Madagascar, has joined the betalain family tree. Because betalains and anthocyanins have never been detected in the same plant tissue in angiosperms, studying their evolutionary history is very fascinating (Mabry and Dreiding 1968; Strack et al. 2003; Cai et al. 2005; Grotewold 2006). Betalains are also produced by fungi such as *Amanita, Hygrocybe*, and *Hygrophorus* (Delgado-Vargas et al. 2000).

22.4.1 Betalains in Different Beet Varieties and Cultivars

Beetroot colour varies based on cultivars, varieties, growth circumstances, age, and size. The timing of harvest influences the pigment concentration; late harvest results in greater colour (Nilsson 1973). Gasztonyi et al. (2001) investigated the pigment content of five distinct types of red beet. The red–violet pigments betanin, isobetanin, betanidin, and isobetanidin were detected, with betanin being the most abundant (0.4–0.50 g/kg) and vulgaxanthin I being the least abundant (0.32–0.42 g/kg) (Table 1.6). There was not much difference between the kinds.

Nilsson (1970) of Sweden investigated the development of pigments and the size of red beets in three varieties: Banco, Egyptian-Platronde, and Rubia. The time of planting and harvesting had an influence on pigment concentration, according to the researchers. Betacyanin and betaxanthin concentrations were lower in June than in September/October. More yellow pigment was obtained in future harvests as betacyanin and betaxanthin levels climbed and peaked in August and the autumn. As the diameter of the beet increased, the quantity of red and yellow pigment decreased. Pigment levels in little beets were greater than in giant beets.

22.4.2 Biotechnology for the Production of Betalains

As early as the 1980s, the presence of colours in red beet tubers drew the attention of many scientists who were studying plant tissue culture for the synthesis of secondary metabolites. This is because pigments are visible (Akita et al. 2000, 2001) and can be easily quantified using spectrophotometry. Hairy root cultures derived from genetically modified beets are now commonly employed in the commercial production of red beet colours (Pavlov et al. 2002; Georgiev et al. 2010a; Thimmaraju et al. 2003a, b, 2004, 2006; Pavoković et al. 2009). Additionally, these technologies appear to provide better control over pigment quality, as production appears to be independent of environmental factors, which cause large variations in field-grown beets (e.g. up to a 250% increase in betanin content even in sugar beets) (Pavoković et al. 2009).

However, there have been reports of substantial chemical variations between the two sources. Rutin, for example, was only detected in extracts from hairy root cultures, while chlorogenic acid was only found in extracts from field-grown plants (Georgiev et al. 2008). The greater antioxidant activity of the hairy root extract compared to the field-grown beetroot extract (Georgiev et al. 2010b) was attributed to its higher quantities (20-fold) of total phenol chemicals, which may have a synergistic impact with the betalain pigments in the beetroot.

22.4.3 Extraction of Red Beetroot Pigments

Red beetroots have been the primary source of pigment extraction in all of the trials, whereas beet leaves, stems, and seeds have been utilized just a few times (Gennari et al. 2011; Lee et al. 2009; Ninfali et al. 2007; Pyo et al. 2004; Križnik and Pavoković 2010). Processes for extracting colour from red beetroots may begin by chopping the tubers into little pieces or grinding them quickly, depending on how the tubers were prepared. To maximize the output of betalain pigments while minimizing losses, further processing processes are required; the goal is to produce a long-lasting pigment extract. Extracting pigments from methanol or ethanol solutions (20–50%) is common; however, in certain cases, methanol or ethanol solutions are necessary for full extraction (Delgado-Vargas et al. 2000). Pigments' stability was further enhanced by the addition of ascorbic acid to a somewhat acidic extraction medium in the work of Escribano et al. (2002). The higher pigment stability was revealed to be due to the colour components being more stable and resistant to oxidation, both chemical and by endogenous polyphenol oxidases (PPOs) (Escribano et al. 2002; Strack et al. 2003). For hairy root cultures of yellow beets with high tyrosinase activity, ascorbic acid was required to prevent the loss of betaxanthin and miraxanthin V, as well as the formation of artefacts created by degradation products, as reported by Strack et al. (2003). Additional ascorbic acid was required for hairy samples, according to Strack et al. (2003).

All of these factors contribute to the longer shelf life of the beetroot pigments extracted during spray drying, including ascorbic and iso-ascorbic acids, as well as the absence of metal cations, such as Fe, Cu, Sn, and Al (von Elbe et al. 1974; Azeredo et al. 2007; Azeredo 2009; Haber et al. 1979). Pai and D'Mello (2004) gave a study on the stability evaluations of red beetroot in a range of medicinal and soft beverages (Havlikova et al. 1983). It is claimed that the low electric fields used in beetroot pigment processing and storage are preferable to those used in cryogenic freezing (Kujala et al. 2000; Patkai et al. 1997), which maintains a relatively consistent temperature throughout processing and storage (Kujala et al. 2000). This study was conducted by Zvitov and colleagues in 2003. There have been several studies comparing different methods of extracting beetroot colours, and the findings have been made public (Gasztonyi et al. 2001; Kujala et al. 2001; Vitti et al. 2005).

Even though betalains are highly susceptible to oxidation and temperature, newer technologies such as pulsed electric field treatment, gamma-irradiation, and ultrasound can be used in conjunction with traditional extraction methods such as solid–liquid extraction in order to increase the yield of betalains. Technology may be able to improve pigment yields in the future, since pigments are stored in the vacuoles of cells and are not generally expelled by cells (Cormier 1997). Diffusion, reverse osmosis, and solid–liquid ultrafiltration have all been utilized in small-scale extraction (Wiley and Lee 1978; Wiley et al. 1979; Lee et al. 1982). Sugars and nitrogenous chemicals, which make up 80% of beet juice, are eliminated during fermentation to boost betanin content in the final product. In general, smaller beets are preferred than bigger beets because they contain more betalain. Milling, followed by the addition of citric acid to the resultant mash, is a common way of producing tissue combination (gradual size reduction). It is possible to reduce the pH of the filtered juice in order to inhibit PPOs, although peroxidase may remain active until the juice is heated above 75 °C. Acidity and a lower heat load (pasteurization rather than sterilization) are sufficient to ensure microbiological stability while minimizing pigment degradation. Additionally, ultrafiltration has shown to be a beneficial method of purification. The use of pulsed electric fields to remove pigments is a relatively new technique that has yet to be widely used in the manufacturing sector. Food colouring beets with high pigment concentrations but low solid contents have been proposed. A betalain recovery rate of less than 50% may be achieved by using macerating enzymes in the hydraulic pressing process; however, this method has been improved by the inclusion of these enzymes. Some drawbacks of red beet extract include its wide spectrum of colours and its earthy, beet-like aroma. Because of the high molar absorption capacity of betalains, only modest amounts of pure pigments (50 ppm betanin) are needed for the majority of uses. In addition, the beet extract has a low tinctorial power because of its high carbohydrate content. As a result, the possibility of fermenting red beet juice with various yeast species has been examined. The pulsed electric field (PEF) approach may be used to successfully separate pigment molecules from total extract in addition to mechanical separations. Results from traditional PEF treatment were equivalent to those reported by Loginova et al. (2011) when they utilized trains of monopolar rectangular 100-m s pulses with electric field intensity $E = 375–1500$ V cm. Between 30 and 80 °C was the range of temperatures in use. The application of PEF treatment may speed up and shorten the extraction time of betalains, according to research. The enhanced colourant release during aqueous extraction has been linked to electroporation. It took just 1 h of treatment at 80 °C to completely deteriorate the colourant, whereas the rate of colourant degradation at 30 °C was minimal after 5 h of treatment. Following treatment with PEF, diffusion with a low activation energy was shown to be the most important regulator of extraction process. Pigment degradation was slower at temperatures ranging from 30 to 50 °C.

22.4.4 Encapsulation of Beet Juice

The impact of various carriers, maltodextrin, gum acacia, and soluble starch, in varied percentages, with freshly extracted beetroot juice was investigated during spray drying, where the chamber temperature ranged from 150 to 165 °C (Koul et al. 2002). The amount of carriers added to the extract was shown to be indirectly related to the % yield of betalain. The spray-dried betalain dry powder's shelf-life tests over 180 days revealed that the spray-dried product was stable at temperatures ranging from 4 to 20 °C.

22.4.5 Macronutrients

Various studies have shown that the nutritional content of fresh beetroot differs depending on the variety, genetics, environmental circumstances, and harvesting procedures used to produce it. Beetroot includes carbs (9.96 g/100 g), including starch, fructose, sucrose, glucose, and dietary fibre; protein (1.68 g/100 g); and fat (0.18 g/100 g) according to early research. Besides carbs (5 g/100 g), starch (4.5 g/100 g), and protein (14.8 mg/100 g), the fruits and leaves also include a variety of other nutrients (Agarwal and Varma 2014; Richardson 2014). Beetroot has a significant quantity of both necessary and non-essential amino acids, making it an excellent source of protein/100 g of edible portion. The following amino acids are present: tryptophan (0.019 g), isoleucine (0.048 g), leucine (0.068 g), lysine (0.058 g), threonine (0.047 g), methionine (0.018 g), phenylalanine (0.046 g), tyrosine (0.038 g), valine (0.056 g), and cystine (0.046 g) (Nemzer et al. 2011). The total saturated fatty acids in beetroot are 0.027% of the total monounsaturated fatty acids (0.032%) of the total polyunsaturated fatty acids (0.060%) of the total polyunsaturated fatty acids (0.060%) and phytosterols (25 mg) in the edible portion per 100 g of edible portion (U.S. Department of Agriculture 2014).

22.4.6 Micronutrients

Vitamins and minerals are among the micronutrients available to us. According to early studies, beetroot contains a variety of vitamins, including vitamin A (2 g), thiamine (0.31 mg), riboflavin (0.27 mg), niacin (0.333 mg), pantothenic acid (0.145 mg), vitamin B6 (0.067 mg), ascorbic acid (3.6 mg), folate (80 g), and minerals, including sodium (77 mg), calcium (16 mg), iron (0.79 mg), phosphorus (38 mg), and potassium (305 mg) (Yashwant 2015). In addition, beet leaves are more nutritious than beetroots in terms of nutrients. Beetroot leaves contain vitamins such as vitamin A (3.93 mg) and vitamin K (280 mg), as well as minerals such as calcium (2220 mg), iron (16.90 mg), magnesium (350 mg), potassium (1400 mg), and phosphorus (330 mg) per 100 g of edible portion. Beetroot leaves also contain vitamins such as vitamin A (3.93 mg) and vitamin K (280 mg). In addition to being used to lower blood pressure, which is essential for cardiovascular health, they are also employed in the battle against cancer. The efficacy of protein extraction (Agarwal and Varma 2014), biochemical screening of beetroot leaf (Maraie et al. 2014), and antibacterial and antioxidant properties of beet plant extracts (Agarwal and Varma 2014) were also found in a recent research study (Richardson 2014).

22.4.7 Phenolic Compounds

Phenolic chemicals are a wide family of plant secondary metabolites that are important for the nutritional integrity of plant-based meals. Beetroot has a significant concentration of phenolic chemicals as well as flavonoids. On average, 50–60 mmol/

g dry weight phenolic acids have been found in beetroot, according to published research (Kathiravan et al. 2014). Furthermore, beetroot peel has the second highest dry weight content of total phenols after grapefruit peel. There were several betalains found in the red beetroot peel, including vulgaxanthin I and II, indicaxanthin, prebetanin, isobetanin, betanin, and neobetanin, all of which were highly unstable phenolic compounds. The most notable of these was 5,50,6,60-tetrahydroxy-3,30-biindolyl, a dimer of 5,6-dihydroxyindole. The beetroot seed wall also contained two phenolic amides, *N trans*-feruloyltyramine and *N trans*-feruloylhomovanillylamine, which were separated and studied further (Nemzer et al. 2011). This variety of *Beta vulgaris* has been shown to have large amounts of hydroxybenzoic and hydroxycinnamic acid derivatives, the two main families of phenolic acids, according to research. Epicatechin, catechin hydrate, rutin, vanillic acid, *p*-coumaric acid, protocatechuic acid, caffeic acid, syringic acids, proline, and monoterpene dehydrovomifoliol are some of the phenolic acids found in plants (Maraie et al. 2014). The presence of phenolic compounds in betalain extracts from intact *B. vulgaris* cv. Detroit Dark Red plants was discovered. The extract of Detroit Dark Red plants contains 4-hydroxybenzoic acid (0.012 mg/g), chlorogenic acid (0.018 mg/g), caffeic acid (0.037 mg/g), catechin hydrate (0.047 mg/g), epicatechin (0.032 mg/g), and rutin (0 mg/g), whereas the high antioxidant activity of the hairy root extract was associated with increased concentrations (more than 20 fold) of total phenolic concomitant compounds, which have synergistic effect with betalains (Georgiev et al. 2010a). The phenolic contents of Detroit beetroot pomace extract were determined using high-performance liquid chromatography (HPLC). The results revealed that ferulic acid (132.52 mg), vanillic acid (5.12 mg), *p*-hydroxybenzoic acid (1.13 mg), caffeic acid (7.11 mg), protocatechuic acid (5.42 mg), catechin (37.96 mg), epicatechin (0.39 mg), and rutin (0.25 mg) were present. To determine the total phenolic content of beetroot, Vasconcellos et al. (2016) evaluated the total phenolic content of beetroot juice, chips, powder, and cooked beets. Phenolic chemicals are found in the least amount in the root portions of most plants. Beetroot juice (3.67 GAE mg/g) and cooked beetroot (2.79 GAE mg/g) were found to have greater total phenolic content values than beetroot chips (0.75 GAE mg/g) and powder (0.51 GAE mg/g), which was attributed to the loss of compounds during the drying process of the vegetables.

22.4.8 Flavonoids

Flavonoids are physiologically active chemicals that have a high antioxidant capacity and provide a wide range of health advantages (Chhikara et al. 2018). According to Vulic et al. (2013), the major flavonoids found in beetroot were betagarin, betavulgarin, cochliophilin A, and dihydroisorhamnetin, with betagarin being the most abundant. Betagarin (5,2-dimethoxy-6,7-methylenedioxyflavone) and betavulgarin (2′-hydroxy-5-methoxy-6,7-methylenedioxyisoflavone) were discovered in beetroot leaves and were shown to be flavanones. Betagarin is a flavanone that is found in beetroot leaves. Other flavonoid compounds isolated from beetroots were 3,5-dihydroxy-6,7-methylenedioxyflavone, 5-hydroxy-6,7-methylenedioxy flavone, 2,5-dihydroxy-6,7-methylenedioxyflavone, 2,5-dihydroxy-6,7-methylene dioxyisoflavone, and 7-methylenedioxyisoflavone (Lim 2016). The flavonoids quercetin, rutin, and 4′-hydroxy-5-methoxy-6,7-methylenedioxyflavone were discovered in the ethyl acetate fraction of *B. vulgaris* ssp. perennis (Maraie et al. 2014).

22.4.9 Saponins

Saponins are bioactive molecules generated by plants to combat diseases and herbivores. They are also known as phytochemicals. *B. vulgaris* has been shown to have 11 triterpene saponins, according to early research. All of the saponins were oleanolic acid derivatives, which was a rare occurrence. Among the betavulgarosides identified were those in the roots (betavulgarosides I through IV), the leaves (betavulgarosides V through VIII), and the roots (betavulgarosides I through VIII). The leaves (betavulgarosides I through X) were found to contain betavulgarosides I through X (betavulgarosides I through X) (Mroczek et al. 2012; Lim 2016). The researchers also discovered 26 triterpene saponins in beetroots, including 17 that had not previously been reported in beetroots and 7 triterpene saponins that were recognized as novel compounds by Mikolajczyk-Bator et al. (2016).

22.4.10 Phytochemicals

It was discovered that the phytochemical 5,5,6,6-tetrahydroxy-3,3-biindolylandin was present in the peel extract of *B. vulgaris* var. *cicla* and that norisoprenoids (+)-dehydrovomifoliol and 3-hydroxy-5,6-epoxy-ionone were present in the aerial portions of *B. vulgaris cicla* (Lim 2016). Beetroot was used to isolate a poly 3-hydroxyalkanoate component, which was comprised of 3-hydroxybutyrate with a molecular weight of 9124 Da and a polydispersity index (PDI) of 1.01, which was recovered from the root (Lim 2016). Beetroot leaves contain beetins, which are type 1 ribosome-inactivating proteins that are virus inducible (Iglesias et al. 2015). Beetins are comprised of a single polypeptide chain with variable degrees of glycosylation (Iglesias et al. 2015). Because of the physiological effect of these chemicals on the human body, they are very important in maintaining human health.

22.4.11 Carotenoids

In addition to being responsible for the various hues of fruits and vegetables, carotenoids also play an important role in the prevention of fatal illnesses such as cancer and heart disease. Carotenoids, which are found in beetroot, have antioxidant, anti-carcinogenic, and immunostimulant properties. Beetroot has a high concentration of carotenoids, which are powerful antioxidants. It has been shown that they exhibit mutagenesis inhibition action, which is responsible for the reduced risk of cancer (Sardana et al. 2018). Beetroot leaves contain beta-carotene as well as oxygenated derivatives known as xanthophylls, which include lutein, a powerful antioxidant. Beetroot has 1.9 mg of carotene per 100 g, according to Rebecca et al. (2014).

22.4.12 Food Applications

Since red beets were domesticated and cultivated, people have been eager to learn more about the benefits of red beet extract. Since the start of the twentieth century, betalains have been used as a food colouring ingredient. One of the oldest culinary applications of pokeberry juice was to make red wine more colourful by adding it to the liquid. In most countries, regulation restricts commercial availability of betalains to red beet extract juice or powder for the time being. In Europe and North America, beet juice concentrate or beet powder may be used as a food ingredient, in medicinal and cosmetic products, and in cosmetics. The only betalain source approved for food usage in the United States is red beet (Code of Federal Regulations, 21 CFR 73, 40). In addition to its antioxidant, anti-inflammatory, hepatoprotective, and anticancer properties, betalains have a wide range of other positive biological effects. Because they are vacuum-dried to 60–65% total solids, vegetable juice concentrates, including beet colours, are marketed and categorized as vegetable juices in the United States. After spray drying, maltodextrin is often used to dry beet powder. As stated by the maker, the product comprises 0.3–1% betalains, 75–80% of carbs, and 10% of protein even with the addition of macerating enzymes; hydraulic pressing still yields less than 50% betalain recovery. Approximately one-quarter of the $1 billion food colourant business is accounted for by natural pigments. However, synthetic colouring compounds have been phased out in favour of natural colouring agents (Fletcher 2006). Betalains may be found in a wide variety of foods, including dairy products, fruit fillings for bread, relishes, fast food, desserts, and meat replacements and sausages. Beetroot colour is also used in the pharmaceutical sector as a colourant in medication formulations, and it may be found in both solid and liquid forms (Pai and D'Mello 2004).

Betalains must be stored in a dark, oxygen-free environment for an extended period of time with little heat treatment and water activity (Rayner 1993). It was surprising to see that a temperature treatment at 85 °C for 8 h had an impact on the red colour pattern in fresh juice. In a split second, the initial 358° hue angle was changed to 62° and the outcome was a yellow–orange solution (Herbach et al. 2004). A combination of high-performance liquid chromatography (HPLC) and mass spectrometry revealed that the creation of yellow neobetanin and orange–red betanin degradation products was to blame for this shift in betanin pigment colour (MS). Neobetanin has never before shown to be synthesized as a result of heat exposure using HPLC and mass spectrometry. After heat treatment, the orange colour of red beet juice was found to be due to the presence of these compounds (Herbach et al. 2004). Because their degradation necessitates the use of water, betalains are very stable even when there is little water activity present. Spray drying of betalains has been shown to be a feasible method of drying them. Betalain decomposition has been widely investigated in relation to the impacts of water activity, temperature, and oxygen (von Elbe 1975; von Elbe et al. 1974; von Elbe and Attoe 1985).

To mention a few, beet extracts have a strong beet aroma, a wide colour range, and a poor ability to produce colour. However, despite the fact that these water-soluble pigments are well suited for colouring low-acid foods and are stable between pH 3 and 7, betalains are seldom used in food colouring applications. Concentrations ranging from 0.1% to 1.0% of beet concentrate are employed to achieve strawberry colours. For years, beet concentrate has been used in everything from yoghurt to drinks to ice cream to hard candies to salad dressings to cake mixes to ready-to-eat meat items and meat substitutes to gelatin desserts and powdered drink mixes. Stability is why they are used in certain scenarios. Red beet extracts have a broad range of variability and an earthy odour, two of its most significant downsides. Depending on the genotype of the plants used to extract the pigment, the colour of food containing betacyanin may vary from a purplish-red to an orange-red (Cai et al. 1998). At high temperatures (>40 °C), heat-sensitive betaxanthins, which give food a yellowish red colour, have been demonstrated to be as unstable as red betacyanins; however, they are stable at 40 °C when exposed to air and light. After 20 weeks of storage at 22 °C, dried betaxanthins showed 95.6% pigment retention compared to liquid solutions that were comparable (12.5%). At 4 °C, aqueous betaxanthins retained 76.2% of their colour for 20 weeks, indicating that refrigeration improved pigment retention. In a study, it was shown that adding specific chemicals to betacyanins in a purple pitaya (*Hylocereus polyrhizus*) juice matrix increased the fruit's structural and colour stability (Herbach et al. 2006). Purple pitaya juice boiled at pH 4 with 0.1% ascorbic acid was shown to have the highest betacyanin stability outcomes when supplemented with a matrix of matrix components. Hydrolytic breakdown of the aldimine link was assisted by pH 6, whereas decarboxylation and dehydrogenation were encouraged by pH 4. Only a little amount of betacyanin was recovered in the pigment-enriched solution without a juice matrix, while the juice matrix recovered most of the betacyanin. For effective pigment regeneration to take place, a 24-h period of cold storage after heat treatment is required.

For the particular product under consideration, the half-life durations and percent colour retention values of anthocyanin and betalain extracts were adequate, and these extracts were successfully applied to cheeses (Prudencio et al. 2008). The influence of beet and honey on the quality characteristics and carotene retention of carrot-fortified milk product during storage at 30 °C was studied on the basis of changes in pH, free fatty acids, and sensory quality (Bandyopadhyay et al. 2008). Adding beet juice and honey to the product had a synergistic effect, showing that they lowered the acidity and amounts of free fatty acids in the product. When honey was used in the mix, the outcome was a better tasting product. This study found that combining equal parts beet and honey in a carrot-fortified milk product improved quality and retained carotene significantly.

22.5 Parsnip

Pastinaca sativa L. ($2n = 2x = 22$) is a biennial native to Europe and western Asia that is grown for its huge, meaty taproot. The Romans and Greeks employed it for medical and culinary uses in ancient times. Flowers are protandrous and show mild inbreeding depression. It belongs to the Umbelliferae (Apiaceae) family. Like carrots, parsnip blossoms are corymbs. They are generally cross-pollinated by putting both parents' heads in a sack and adding blowflies. Markers are used to identify self-seeds. Hand pollination and emasculation are almost impossible. Despite this, Cimbal reported efforts at hybridization and variance in the set of seed in various kinds following emasculation and pollination. The development of white-fleshed roots, low incidence of fanging, resistance to bruising, smooth skin, shallow crowns, bulbous wedge-shaped root or medium to small, thin wedge-shaped to bayonet-shaped roots suitable for prepacking or canning, and resistance to canker and other important diseases and insect pests are the main objectives of parsnip improvement.

22.5.1 Nutritional Status

Parsnip is used in cuisine, including as a component in baby food and as a cattle feed (Hutschenreuther et al. 2009; Ostertag et al. 2002). Due to the presence of a number of minerals and vitamins, parsnip is a highly adaptable vegetable with a broad range of health advantages. Minerals such as phosphorus, potassium, magnesium, manganese, zinc, and iron are found in it. Parsnip is high in folate, as well as vitamins B, C, E, and K, all of which are helpful to human health. The dietary fibre level of parsnip roots is high. Dietary fibre levels in parsnips have been found to be as high as 4.7–4.9% (wet basis) in certain studies (Siddiqui 1989; Southgate 2001). This feature is of particular significance since Western nations have a growing need for fibre in their regular diets.

22.6 Rutabaga

Rutabaga is a frequent American English word for the plant *Brassica napus* var. *napobrassica*, but swede is the favoured term in the majority of England, Australia, and New Zealand. Although it is a cool-season frost-tolerant crop, its output is highest in northern Europe and the United States, as well as in the United Kingdom and Canada (Welbaum 2015). It is one of around 3500 species in the Brassicaceae family (Jahangir et al. 2009; Sasaki and Takahashi 2002). The root is cheap and extensively used as a food and spice in northern Europe, northern America (Pasko et al. 2013), China, Japan, and India, while the seeds provide vegetable oil (Kusznierewicz et al. 2008). The root pulp is white to orange-yellow in colour and has a sweet and mildly peppery flavour. It may be baked, boiled, or grilled in foil over coals. Rutabagas are grown as a winter cover crop, and its leaves and roots are used as cattle feed. The roots may also be eaten as a table vegetable and the leaves as a leaf vegetable. The “root” of the rutabaga is a swollen portion of the hypocotyl and higher roots. The crop’s virtues for human consumption have been rediscovered in recent decades, and rutabaga may be shredded and eaten raw, or sliced into pieces and used in soups, stews, or food recipes (Rydenheim 2008). Consumption might be harmful. Rutabaga can be introduced as a fresh-cut product to boost sales even more (Helland et al. 2016; Zhu et al. 2002).

Rutabagas include 52 calories, 1.5 g of protein, 12 g of carbohydrate, and 0.2 g of fat per cup (140 g). Rutabagas have a low glycaemic index and are a good source of vitamin C, potassium, and phosphorus. The USDA provides the following nutritional information for one cup (140 g) of uncooked rutabaga cubes. Rutabagas are high in vitamins and minerals. A one cup serving provides the following minerals: potassium (427 mg), phosphorus (74 mg), iron (0.6 mg), magnesium (28 mg), calcium (60 mg), and zinc (0.3 mg). A single-cup serving of rutabaga also contains many vitamins: vitamin C (35 mg), thiamine (0.13 mg), vitamin B6 (0.14 mg), folate (29 μg), niacin (0.98 mg), riboflavin (0.06 mg), and vitamin E (0.42 mg). Rutabaga’s complex antioxidant component makeup is perhaps its most essential function. Sulphur-containing chemicals known as glucosinolates have been demonstrated to slow the development of malignant tumours in the body. Furthermore, large quantities of carotenoids and vitamin C work as antioxidants, preventing the transformation of healthy cells into malignant ones, among other things.

Rutabagas may help to prevent premature ageing, enhance vision, and promote healthy cell regeneration in our organs and tissues. Rutabagas, like other cruciferous vegetables, are rich in fibre, with each serving supplying more than 12% of your daily need. Dietary fibre has a number of roles in the body, but the most important is that it aids in digestion by bulking up stool and reducing constipation and gastrointestinal discomfort. Maintaining a regular schedule is beneficial to your general health as well as your weight-loss goals. Rutabagas are recommended as a low-calorie, nutrient-dense food source in weight-loss diets, and its high fibre content helps lowering the likelihood of overeating. As previously stated, vitamin C is the most abundant vitamin in rutabagas, with a single serving containing more than half of our daily vitamin C need. Vitamin C is required for a variety of body functions, including immune system activation and production of white blood cells. Additionally, vitamin C is required for the creation of collagen, which aids in the growth and mending of skin tissue, muscles, and blood vessels. A lot of research outcomes have shown that high doses of vitamin C may assist in directly preventing colorectal cancer. Rutabagas are high in zinc, calcium, magnesium, manganese, and phosphorus, all of which are essential for bone tissue formation and preservation. Osteoporosis affects millions of people worldwide, however strong and healthy bones can help in avoiding this age related disease to a greater extent. Rutabagas are a good alternative for many vegetarians since they almost give a complete protein, which is difficult to come by when you do not eat meat. Proteins and amino acids are the building blocks of new cells and are required for normal development, growth, healing, reproduction, muscular contraction, and a variety of other biological functions.

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