Chapter 1
Disposal of Agricultural Waste and Its Effects on the Environment, Production of Useful Metabolites and Energy: Potential and Challenges

Jaya Arora, K. G. Ramawat, and Jean-Michel Mérillon

Abstract Agricultural waste and by-products are generated by all activities related to cultivation of crops; vegetable and fruit production and processing; and dairy, poultry, aquaculture and meat production associated with intensive agriculture practices and use of fertilizers. Management of crop residue requires reliable forecast about crop residue to be generated in each season/crop-wise and related policies of the government to handle this biomass. The ever-increasing world population requires increased food and fodder supply which results in increased agricultural waste biomass production. If this biomass is efficiently and wisely used for obtaining value-added products and useful material, this will not only utilize this surplus biomass but also solve many problems of pollution and simultaneously increase the income of farmers. Instead of burning and releasing sequestered carbon in the atmosphere, biomass can be channelled to useful products like antioxidants, charcoal, polysaccharides, peptides, polyphenolics, fertilizer, compost, animal feed and biofuels and developing various technologies for composite materials and innovative uses. A significant quantity (~30%) of food produced globally (1.3 billion tonnes) is wasted due to one or the other reasons, particularly of fruits and vegetables as compared to cereals, root and tuber crops, dairy, beverages, etc. Proper utilization of available resources will solve many socio-economic as well as environmental problems and help in improving living of people in rural areas particularly in developing countries. Plant-based residue or biomass generated by agricultural activities and agriculture-based industry is briefly presented as problem, and remedial measures are required for the benefit of both environment and farmers. In this

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K. G. Ramawat et al. (eds.), *Agricultural Waste: Environmental Impact, Useful Metabolites and Energy Production*, Sustainable Development and Biodiversity 31,
https://doi.org/10.1007/978-981-19-8774-8_1

chapter, we have discussed briefly the impact of agricultural waste on the environment, obtaining useful metabolites and products from it, and emerging novel technologies.

Keywords Agricultural waste · Agroindustrial waste · Value addition · Useful metabolites · Products from agriculture waste · Pollution · Nanomaterials

1.1 Introduction

Agricultural wastes are defined as the residues from the growing and processing of raw agricultural products such as fruits, vegetables, meat, poultry, dairy products and crops (Obi et al. 2016). This agricultural waste is generated by all activities related to cultivation of crops; production of vegetables and fruits, dairy, poultry, aquaculture and meat; and use of intensive agriculture practices and fertilizers. Instead of burning and releasing sequestered carbon in the atmosphere, biomass can be channelled to useful products like antioxidants, charcoal, polysaccharides, peptides, polyphenolics, fertilizer, compost, animal feed and biofuels and developing various technologies for composite materials and innovative uses (Fig. 1.1). Even after utilizing crop residues for different purposes, about 30% (~234 million tonnes/year) is available as surplus in India (Devi et al. 2017). It is consequential that, ever-increasing population require increased food and fodder supply and resultantly increased agricultural waste biomass production. If this biomass is efficiently and wisely used for obtaining value-added products and useful material, this will not only utilize this surplus biomass but also solve many problems of pollution and simultaneously increase the income of farmers. Recently, the circular bioeconomy is gaining momentum which can offer reliable methods to reuse the organic wastes and minimize the

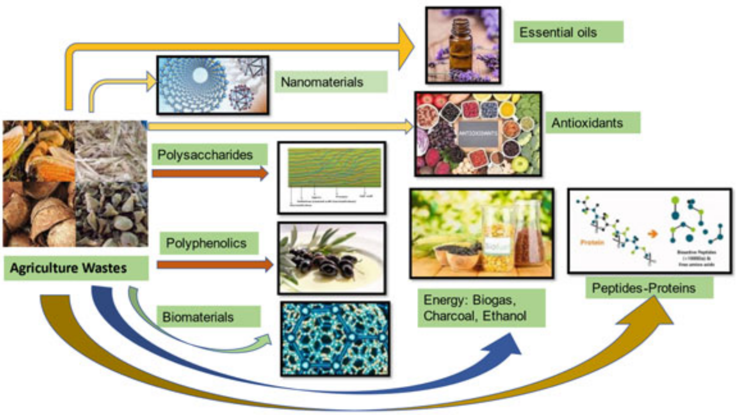

Fig. 1.1 Scope of agriculture waste in obtaining value-added products. The schematic was created using public domain images obtained from open-source database

pressure on traditional sources (Awasthi et al. 2022). In this chapter, we have discussed briefly the impact of agricultural waste on environment and possibility of obtaining useful metabolites with the help of novel technologies as depicted in Fig. 1.1. Details about these products are given in different individual chapters, hence very briefly presented here.

1.1.1 Population Growth and Demand for Food

World population is increasing at a steady rate and likely to cross 9 billion marks in 2050 or 11 billion marks in 2100 (Koop and van Leeuwen 2017; Vollset et al. 2020). Overall, the world's population is three times higher than it was in the mid-twentieth century. Though the growth rate is declining, the global population is still increasing (United Nations Department of Economic and Social Affairs, Population Division 2022, Fig. 1.2). For ever-increasing population with higher food demands, intensive agriculture is being used to produce higher crop yields per hectare and resultantly higher agro-waste. This biomass requires proper management and disposal to avoid many problems. Food consumption is measured as kcal/person/day to assess the evolution of the world food situation and social status. This consumption is increased to ~2800 kcal/day/person in the last three decades associated with

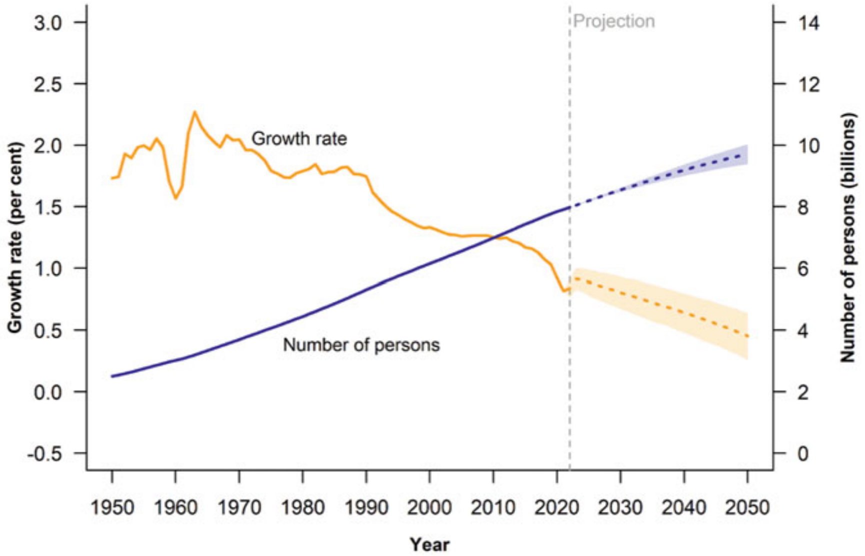

Fig. 1.2 World population and suggested increase in billions during 1950–2050 along with growth rate (United Nations Department of Economic and Social Affairs, Population Division (2022). Figure is reproduced under a Creative Commons license (CC BY 3.0 IGO) http://creativecommons.org/licenses/by/3.0/igo/)

increased population (Alexandratos and Bruinsma 2012). Tremendous pressure is exerted on all available resources to produce optimally to feed this population.

The world population is increasing, particularly in developing countries associated with poverty and unhygienic conditions. All efforts to improve the living conditions are rendered useless due to this population explosion, and to meet the challenge of feeding this hungry population is a herculean task for the agriculture scientists. After World War II, Food and Agriculture Organization (FAO) was created to tackle the problem of hunger and food supply worldwide. The development of dwarf varieties for rice and wheat contributed significantly to increasing the food grain production, particularly in developing countries like India and Mexico (Duque-Acevedo et al. 2020). To achieve SDG2 (Sustainable Development Goal 2; zero hunger) with this ever-increasing population is a challenging task for farm scientists. The balance between nutritious food production and farmer income is also an important factor (Esquivel et al. 2020). Integration of principles of agroecology, organic agriculture and regenerative agriculture is an important concept to develop a sustainable agriculture to feed this population (Giller et al. 2021). Population growth control with efficient management of agroindustrial waste is the need of hour. Therefore, sustainable utilization of all available resources is required.

1.1.2 Impact on Global Warming

Like many developmental activities, agricultural activities are also responsible for causing environmental pollution. Agriculture and agriculture-based industries produce enormous biomass which results in various types of pollution problems. Burning of straw after kharif crop harvest, particularly in Northern India, reached at an alarming state. The use of pesticides and fertilizers and the use/release of water and waste generated by agricultural activities are responsible for pollution of soil, water and environment. The challenge has become difficult in changing environment due to global warming and situation like the recent pandemic. The production of sufficient food grains consumes about 30% of energy produced which consequently impacts global warming. This results in endless cascade of events leading to harmful impacts on soil, water, energy and human health. Increasing the renewable energy crops (biomass, charcoal, energy) competes with land usage for food crops, and a balance between the two is required (Gontard et al. 2018; Joshi et al. 2019). Agricultural activities lead to global warming by promoting various gases like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) release in the atmosphere. This has direct effect on pollution and global warming. The world consensus has developed to reduce carbon dioxide emission to 6000 megatons by 2030. Similarly, India and China have agreed to reduce methane production in rice fields by 26%. Therefore, disposing this agro-waste in eco-friendly manner will mitigate the pollution and global warming by using the biomass for the production of biofuel (biodiesel, bioethanol, biogas, biohydrogen) and bioenergy and valorization of lignocellulosic residues by producing value-added products like biofertilizers,

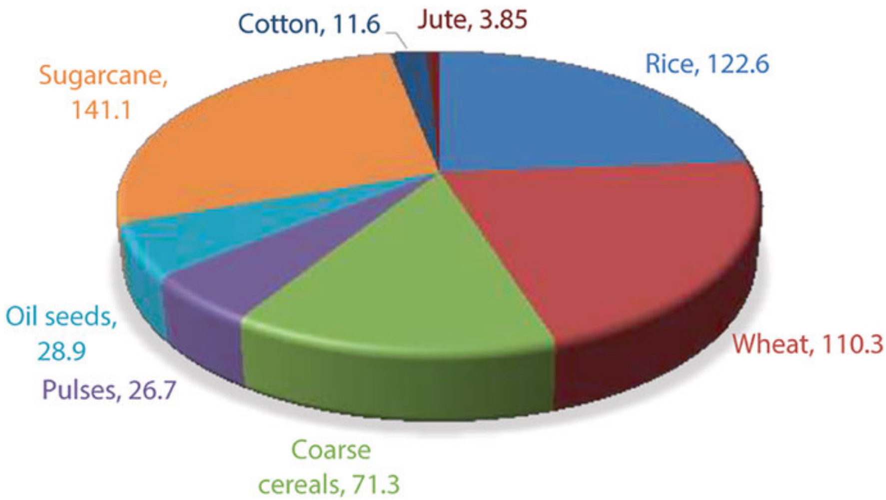

Fig. 1.3 Total crop residue generation in India; million tonnes per year. (Based on data from Devi et al. 2017)

bio-bricks, bio-coal, bio-plastics, paper, industrial enzymes, organic acids, etc. (Elbasiouny et al. 2020; Koul et al. 2022).

The total crop residue accounts for almost 50% of crop biomass produced which is far greater than any other biomass like wood, municipal waste, etc. (Elbersen et al. 2012). In developing countries like India, holdings are small, and technological inputs for cultivation as well as utilization of residual biomass are low. This results in utilization of crop residue mostly for animal feed or burning resulting in increased pollution. Biomass residue generated in India for principal crops and residue burnt are given in Figs. 1.3 and 1.4. Because of this abundance of available biomass, research activity about its utilization has increased exponentially in the last decade as reflected in surge in publications (Duque-Acevedo et al. 2020). Being large agricultural countries, most of the research publications on utilization of agriculture waste were published from the USA, China and India on crops like maize and wheat. A key role in developing sustainable agriculture has come from the international regulatory framework in developing policies by various governments, who also fund for research in this direction leading to developing technology for novel products.

The major impacts of crop residue burning are as follows: (a) emission of greenhouse gases and soot particles, (b) loss of plant nutrients and biodiversity, (c) mortality of active beneficial soil bacteria, (d) loss of soil nutrients and fertility, (e) loss of flora and fauna and (f) soil hardening and erosion due to no cover. Storage and availability of carbon in soil is determined by environmental factors, transformation processes and biotic interactions such as temperature, soil moisture and water saturation, texture, topography, salinity, acidity, vegetation and biomass production (Navarro-Pedreño et al. 2021). Burning of crop residues not only sends carbon in atmosphere but also deprives soil from it. Burning of stubble in November has

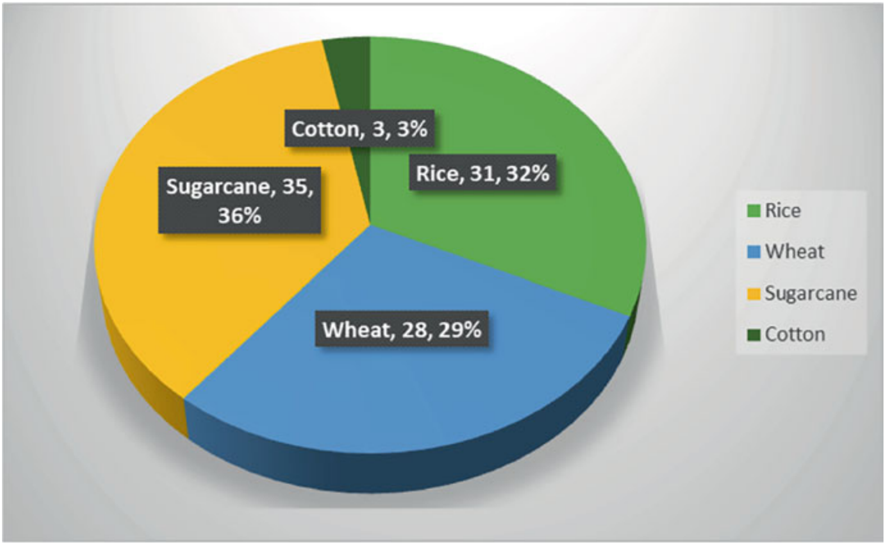

Fig. 1.4 Crop residue burnt in India; million tonnes per year

become major recurrent problem in Northern India and has become bone of contention between neighbouring states. Widespread smoke in Northern India is shown in many satellite images of NASA (Fig. 1.5). Therefore, a permanent solution of this problem is required, and alternative use of this biomass can resolve the issue.

1.1.3 Problems of Management of Residue

Management of crop residue requires reliable forecast about crop residue to be generated in each season/crop-wise and related policies of the government to handle this biomass. Since in most of the Third World countries, crops are rain-fed, forecast about rains, sowing time and seed availability are crucial for yield forecast. The by-products of crops should be used till all valuable products are not obtained and remaining residue ends up in soil. The term 'circular economy' is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible. Efficient conversion of agriculture residue into biogas and fertilizer has its own pros and cons, while obtaining useful metabolites is progressing slowing but steadily. Developing new biomaterials from agriculture waste still requires developing appropriate technology and scaling up for industrial production (Gontard et al. 2018; Capanoglu et al. 2022). Complete utilization of agriculture residues in the content of circular economy requires cost-effective and eco-friendly biotechnological methods to utilize products in food, feed, cosmetics and nutraceutical and even health (Costa et al. 2020). Similarly, much of agroindustrial biomass is generated

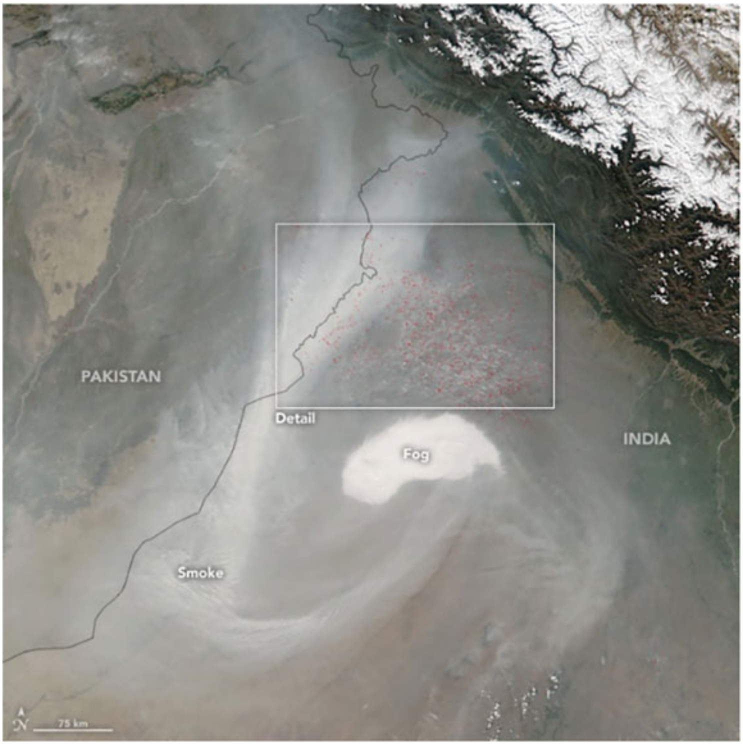

Fig. 1.5 Satellite image showing burning of residual crop (stumps in rectangle) in the fields in Punjab state and smoke and fog pollution in the entire Northern India. (Image courtesy NASA VIIRS image 2017)

from sugarcane industry and fruit and vegetable processing, canned juice production, fruit jam and jelly production and during production of dehydrated fruits and vegetables. These by-products need rapid disposal to avoid further degradation. Conventionally, fruit waste is used for animal feed, as fertilizer and compost. However, new technologies are being developed to obtain useful metabolites from this freely available biomass (see chapters in Parts II and III in this book).

1.2 Agroindustrial and Food Waste and By-Products

A significant quantity (~30%) of food produced globally (1.3 billion tonnes) is wasted due to one or the other reasons, particularly of fruits and vegetables as compared to cereals, root and tuber crops, dairy, beverages, etc. Europe alone produces more than 12 million tonnes of fruit discard every year (Ibarruri et al. 2021). Looking at the 2050 proposed data, increase in population associated with increased food production will result in higher amount of food waste biomass, and it is of utmost importance to utilize this biomass by developing appropriate technology now, which will be perfected and industrialized in the coming decades. Most of the food waste of all types is used for the animal feed or producing compost. If this biomass is used for the extraction of value-added products like essential oils, polyphenols, anticancer compounds, pigments and enzymes or focused on the production of new foods and single-cell protein (SCP), it will impact rural economy (Wadhwa et al. 2013; Rao and Rathod 2019). A selected examples of various and diverse products including speciality chemicals are presented in Table 1.1. The examples shown are from crops, fibre crops, fruits and animal products. Therefore, availability of biomass and developing appropriate technology should be blended to develop high-value products.

Fruit and vegetable processing industries generate large quantities of biomass which is used in compost making and oil and protein extraction depending on the crop and type of fruit processed. If left unattended, it creates pollution and foul odour problems. Microorganisms, particularly fungi, play an important role in conversion of this biomass using solid-state fermentation process as compared to bacteria and insects. Fungi have advantages like high protein content, low nucleic acids and easy penetration and harvest as compared to other organisms (Ibarruri et al. 2021).

1.3 Value-Added Products

Plant cells produce two types of metabolites called primary and secondary/specialized metabolites. Primary metabolites are those which are directly involved in the metabolism like carbohydrates, lipid and proteins where secondary metabolites are end products of primary metabolism such as alkaloids, polyphenolics, terpenes, etc. (Ramawat 2019; Ramawat et al. 2009). After obtaining product of commerce, leftover biomass can be utilized to obtain these metabolites which will eventually lead to value addition to the agriculture produce or industrial process. Each cell of the biomass may contain various protein/peptides, essential oils, resins, polyphenolics or antioxidants. These compounds vary in their chemical nature and present in small quantities, which require specialized techniques to isolate these products (Ramawat and Arora 2021). The bulk of biomass can be reduced to high-value product of small volume facilitating easy handling and reduced transport cost. These include various cell wall components and their derivatives like polysaccharides and alcohols, proteins and peptides, composite produced from these, lignin degradation products and different classes of secondary metabolites, like phenolics, terpenes, alkaloids and pigments (Jimenez-Lopez et al. 2020; Meena et al. 2022). The use of agriculture waste for obtaining high-value products may have many beneficial effects on the environment, sustainable utilization of resources and improvement of socio-economic standards of farmers (Chiocchio et al. 2021).

Table 1.1 Selected examples of commercially viable products obtained from agricultural residues (Anonymous 2020; Kumar et al. 2017; Sadh et al. 2018)

S. No.	Residue/crop	Value-added/recovered products	Benefits/remarks
1.	Agricultural biomass	Biochar by using pyrolysis	Improve soil fertility and crop yield
2.	Almond hull	Pectin, phenolics, pullulan, SCP	Bioactive molecules
3.	Apple: Peel and pomace	Phenolics (epicatechin, catechins, anthocyanins, quercetin glycosides, procyanidins), biochar, biofertilizer, organic acid and enzymes	Bioactive molecules, biofuel, biomethane, bioethanol
4.	Banana, stem and peduncle	Cellulose	Ferulic acid is produced from fibre; value addition
5.	Cashew; 7mMT of cashew apples	Apple powder	Long shelf life, additional income to farmers
6.	Citrus peel	Hesperidin, naringin, eriocitrin, narirutin, galacturonic acid	Bioactive molecules, bioethanol, mucic acid
7.	Cherry pit waste	Cherry waste biomass	Biochar
8.	Crop residues, city waste and horticultural wastes	Phospho-sulpho-nitro (PSN) compost	Improving crop production, soil biological activities and overall soil health
9.	Grapes, pomace, seeds	Phenolics (dihydroxyphenols, vanillic acid, proanthocyanidins, quercetin 3-*o*-glucuronide, quercetin, resveratrol)	Bioactive molecules, value addition
10.	Groundnut shell	Cellulose by using enzyme (up to 70%), biodiesel, bioethanol, nanosheet	Import substitute, rural economy
11.	Kinnow peel	Beverage with nutraceutical properties	Alcoholic beverage with higher nutraceutical properties, proper waste utilization
12.	Kiwi bagasse, skin, seeds	Vitamins, minerals, phenolic compounds	Food, cosmetic and pharmaceutical industry
13.	Lac dye	Anthraquinone (laccaic acid A, B, C, D and E)	Pollution control, as dye
14.	Low-grade jute fibre	Handmade paper/paper board	Impact on deforestation, pollution, rural economy
15.	Lasora (*Cordia myxa*)	Polysaccharide	Value addition
16.	Livestock keratin waste	Protein	Animal feed, biosorbents
17.	Mango, peel and kernels	Antioxidants, pectin and dietary fibre, gallic acid, ellagic acid, gallates, gallotannins, condensed tannins	Value addition, stable antioxidants
18.	Oilseed cakes/meals (example soy meal, groundnut cake)	Protein isolates/concentrates	Value addition, availability of protein

(continued)

Table 1.1 (continued)

S. No.	Residue/crop	Value-added/recovered products	Benefits/remarks
19.	Oyster mushroom	Mushroom cultivation waste	Biocompost, plant growth media, bioenergy, biofertilizers
20.	Potato peel	Amylase, protease, gallic acid, caffeic acid, vanillic acid	Value addition
21.	Pomegranate: Peel and pericarp	Gallic acid, cyanidin-3,5-diglucoside, cyanidin-3-diglucoside, delphinidin-3,5-diglucoside, ellagitannins	Bioactive molecules, value addition,
22.	Rice bran	γ-Oryzanol, bran oil	Bioactive molecules, edible oil, value addition
23.	Shrimp, lobster and crab shells	Glucosamine hydrochloride is a high-end nutraceutical	Value addition
24.	Shrimp processing wastes	Astaxanthin: Carotenoidpigment	Value addition
25.	Soybean (okara: Tofu and soy milk production)	Protein	Eco-friendly disposal of soyprocessing, animal feed
26.	*Sesame* capsule	Pectin	Commercial emulsifier
27.	Tomato waste	Carotenoids	Antioxidants

Table 1.2 Examples of potential of various agricultural wastes for its utilization

S. No.	Agricultural waste	Potential utilization
1	Rice husk ash and charcoal	Additive in cement mix, active carbon
2	Rice husk	Fuel for electricity production
3	Banana peel, sugarcane fibre	Paper making
4	Oil palm fruit residue	Compost, mulching
5	Oil palm stem, rubber plant wood	Particle board
6	Husk, bagasse	Mushroom cultivation
7	Bagasse, discarded banana	Ethanol production, animal feed
8	Husk, bagasse, dung	Biogas, electricity, charcoal
9	Tea waste	Oyster mushroom cultivation

1.4 Valorization of Agroindustrial Waste

Some examples of potential direct utilization of agroindustrial waste are presented in Table 1.2. Some of them are conventionally used, while other technologies are being developed. Besides direct use of agroindustrial waste in different products, selected biomass can be used for obtaining value-added primary metabolites and secondary metabolites.

1.4.1 Various Useful Primary Metabolites Obtained and Processes

All plant tissues are mainly made up of lignocellulose, whereas animal tissues are made of proteins and lipids. Cellulose is the highest plant-based molecule on the planet Earth (chitin from animal world). Huge biomass is generated as crop residue or during processing of fruits and vegetables for direct consumption or for drying, canning, pickles, jams and jellies and juices. Such a discarded plant and animal waste is available for extracting useful primary metabolites such as cellulose, pectin, lignocellulose, peptides, enzymes (amylase, cellulase, pectinase, invertase, xylanase), developing composite, etc., from plants. In animal system, all available resources are utilized for obtaining products like chitin, collagen and whey products. In all these cases, handling, transporting and extracting huge biomass are a costly affair; hence, ancillary industries need to be set up in the vicinity of main food processing industry.

1.4.2 Various Bioactive Secondary Metabolites Obtained

Those secondary metabolites which exert a profound physiological effect in a mammalian system are known as medicinal or bioactive compounds. As stated above, these compounds are present in small quantities in all plant parts, and depending on the type of residue, the chemical nature of these compounds is also diverse. On the basis of their biosynthesis, these are broadly classified as alkaloids, terpenes and phenolics. Some selected examples of bioactive compounds obtained from different industrial food waste residues are presented in Table 1.3.

We have not discussed in detail the individual plant or process here, but a general view is presented. There are several well-known and established agricultural and horticultural crops like *Vitis* (canes, pomace, seeds, skin), olives (branches, leaves, seeds, pomace), mango (fruit peel, seeds), orange (peels, pulp residue), apple (pomace), cashew (cashew apple botanically pedicel), wall nut (shell) and various parts of tea, coffee and cacao, where huge biomass is generated during cultivation and fruit processing (Sadh et al. 2018; Malenica and Bhat 2020; Chiocchio et al. 2021). Enormous residue (peels) generated during fruit processing of tomato, banana and citrus is used for obtaining carotenoids, phenolic acids, flavonols, catechol-amines and essential oils, respectively. There is no common method or process to treat this biomass, and based on chemical nature, a method is adapted, for example, water (solid-aqueous phase extraction) for water-soluble compounds like neutral alkaloids or slightly acidic or basic aqueous extraction for some alkaloids or phenolics. Essential oils are steam distilled, whereas other products may be extracted using microwave-assisted, supercritical fluid extraction or pressurized liquid extraction methods (Sadh et al. 2018; Chiocchio et al. 2021). Another approach to obtain useful metabolites is the use of solid-state or liquid-state fermentation by the use of

Table 1.3 Some selected examples of bioactive compounds obtained from different industrial food waste residues (Kumar et al. 2017; Sadh et al. 2018; Malenica and Bhat 2020; Chiocchio et al. 2021)

S. Nos.	Source residue	Bioactive components
1.	Apple peel and pomace	Epicatechin, catechins, anthocyanins, quercetin glycosides, chlorogenic acid, hydroxycinnamates, phloretin glycosides, procyanidins
2.	Beans	Several isoflavonoids, daidzein, genistein
3.	Carrot peel	Phenolics, carotenoids (beta-carotene, alpha-carotene, etc.)
4.	Citrus fruit peel	Hesperidin, naringin, eriocitrin, narirutin
5.	Coffee beans	Polyphenols (several isomeric caffeoylquinic acids, dicaffeoylquinic acids, feruloylquinic acids and epicatechin, considered as potent antioxidants)
6.	Grape seed and skin	Coumaric acid, caffeic acid, ferulic acid, chlorogenic acid, cinnamic acid, neochlorogenic acid, *p*-hydroxybenzoic acid, protocatechuic acid, vanillic acid, gallic acid, proanthocyanidins, quercetin 3-*o*-glucuronide, quercetin, resveratrol
7.	Green tea	(−)-Epigallocatechin, (+)-gallocatechin, (−)epicatechin-3-*O*-gallate
8.	Guava skin and seeds	Catechin, cyanidin 3-glucoside, galangin, gallic acid, homogentisic acid, kaempferol
9.	Litchi pericarp, seeds	Cyanidin-3-glucoside, cyanidin-3-rutonoside, malvidin3-glucoside, gallic acid, epicatechin-3-gallate
10.	Mango kernel	Gallic acid, ellagic acid, gallates, gallotannins, condensed tannins
11.	Olives	Anthocyanins (cyanidin and delphinidin glycosides), flavanols, flavones, phenolic alcohols (tyrosol, hydroxytyrosol), secoiridoids (oleuropein)
12.	Pomegranate	Gallic acid, cyanidin-3,5-diglucoside, cyanidin-3-diglucoside, delphinidin-3,5-diglucoside, ellagitannins
13.	Potato peels, tomato residues	Glycol-alkaloids
14.	Tomato skin and pomace	Carotenoids (lycopene)
15.	Wheat bran and germs	Phenolic acids, antioxidants

microorganisms. Several species and strains of bacteria and fungi are used for this purpose (Ibarruri et al. 2021; Sadh et al. 2018). Microbial degradation and value addition to the agriculture waste is at the forefront due to sustainable approach (Singh and Singh 2022). Metabolomic profiling of agricultural waste with the help of available high-throughput analytical techniques, such as high-performance liquid chromatography, gas chromatography, mass spectroscopy and NMR, has resulted in isolation and characterization of various bioactive metabolites (Khaksar et al. 2022). The products obtained by such processes provide valuable drugs and therapy products or are used for fortification. As the bulk of biomass is available free/at low cost, commercial viability of the project and products is always high.

1.4.3 Composting of Agrifood Wastes

Agricultural and food wastes are increasing because of high yield of cultivars, technological inputs and feeding increasing population which create pressure on the environment due to methane gas and pathogenic microorganism causing health hazards by reaching ground water and fields. Food waste is a significant contributor to the greenhouse gases and consequently global warming (Al-Rumaihi et al. 2020). Therefore, microorganisms in the composting can be effectively monitored by using modern techniques of molecular marker like biochemical identification, polymerase chain reaction denaturing gradient gel electrophoresis (PCR-DGGE), terminal restriction fragment length polymorphism (T-RFLP), single-strand conformation polymorphism (SSCP), microarray analysis and next-generation sequencing (NGS) (Palaniveloo et al. 2020).

Traditionally, recycling technologies use this waste for landfills, incineration and composting. The use of agriculture waste and food waste can be used for making compost, which is in practice since a long time, but it is generally a local process. Composting requires a close monitoring of the process, and depending on the ingredients, the presence of harmful heavy metals may be a problematic issue. Composting can be improved by various processes and methods like co-composting, addition of inorganic/organic additives, reducing gaseous emissions and use of different microbes (Awasthi et al. 2020). Details of various methods and microorganisms involved can be found elsewhere and are beyond the scope of this chapter (Maheswari 2014).

The degradation of soil quality and fertility due to intensive use of nitrogen fertilizers, industrialization and human activity has resulted in finding ways to improve soil quality (Verma et al. 2022). Biochar has been shown to effectively counterbalance deteriorating soil conditions by way of waste management, C sequestration, reduction of greenhouse gas emission, water and soil remediation and enhancing soil fertility and crop production. The use of biochar produced from agro-waste along with or without organic manure in the field has positive response in amelioration of soil quality and plant growth (Zhou et al. 2022; Haider et al. 2022). However, this is the beginning, and more research data are required before a final conclusion is drawn. More details are given in Chap. 2 in this book.

1.4.4 Renewable Energy Production

Renewable bioenergy like biogas, biodiesel and ethanol can be produced from available agriculture waste without increasing the cultivation land area for energy crops. Consequently, this will also reduce the methane generation if this waste is used for energy production instead of landfills. The use of biodiesel and ethanol in petroleum diesel is priority area in most of the countries to reduce dependence on continuously depleting fossil fuel (Sharma et al. 2017). Agricultural and food waste is mainly composed of lignocellulose (1.5×10^{11} tonnes/annum), and appropriate technology can convert this into ethanol (see Part IV in this book). This lignocellulose has to be converted by hydrolysis into simple sugars so that these sugars are fermented to ethanol by microorganisms (Joshi et al. 2020, 2021). Therefore, technical improvement of hydrolysis, inhibitory effect of residual acids/chemicals, selection of microorganisms to convert pentoses, etc., are major bottlenecks in efficient conversion process of agricultural waste into bioethanol, biobutanol, biogas, biohydrogen and biodiesel (Pattnaik et al. 2019; Panpatte and Jhala 2019; Joshi et al. 2022). Agro-waste biorefineries result in zero waste and are viable, sustainable and eco-friendly processes for converting agro-waste in useful products particularly in developing countries (Dhanya 2022; Duan et al. 2022).

Crop residues, food and fruit waste disposal and waste water from such processes need to be disposed in a manner to not cause harm to water bodies and environment. Waste, by-products and effluents coming from industrial processing and agricultural procedures of vegetables and fruits can be defined as biomass, according to CE directive 2001/77 (Valentina et al. 2014).

1.4.5 Nanotechnology: An Advance Tool

Nowadays, nanotechnology has become an important green technology in valorizing agricultural waste (Capanoglu et al. 2022). Various bioactive compounds present in agriculture waste act as capping and reducing agents and accelerate the synthesis of various nanoparticles such as silver, gold nanoparticles, graphene oxide, solar grade silicon nanoparticles, amorphous silica, carbon and various metallic nanoparticles (Thangadurai et al. 2021). Bio-nanocatalysts, bio-nanosorbents made from agroindustrial biowaste, are being deployed for removing organic and inorganic water contaminants from water bodies and creating a circular economy nexus (Omran and Baek 2022; Abdelbasir et al. 2020). A method was developed using iron oxide nanoparticles from mill scale and applied them in adsorption of dye contaminants from industrial waste water. With an average-sized nanoparticles (55.76 nm), optimum efficiency (99.93%) of adsorption of dye contaminants was achieved (Arifin et al. 2017). Cellulose being abundant biopolymer of agriculture waste can be converted to nano-fibrillated cellulose; a potential biopolymer can be used for rapid drug delivery, stabilizing agent and culturing cells for tissue engineering (Kamel et al. 2020). The bioactive phytochemicals present in agriculture and industrial waste stream can be made available by nanoencapsulation using biodegradable active packaging material (McClements and Öztürk 2022). Porous silica nanoparticles synthesized from rice husk were used in purification of air, mainly removal of CO_2 (Zeng et al. 2017). Further synthesis of various nanomaterials using agricultural waste has been described in detail in Chap. 21 of this book.

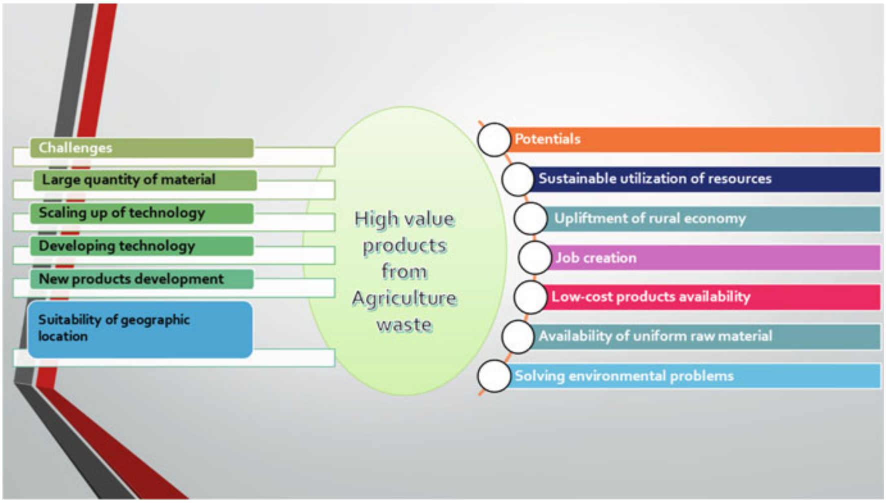

Fig. 1.6 High-value products and metabolites from agriculture waste: challenges and potential

1.5 Conclusions, Prospects and Challenges

The biomass generated by all these agricultural activities is huge, and so is the problem of its utilization and pollution. This requires new environmentally friendly technology development and then scaling up the process to industrial level. Research activities in several directions like biofuel production, biochar and soil amendments, obtaining useful primary and secondary metabolites and producing novel material and composites are priority research trends and new products are developed. In short, challenges and future prospects are presented in Fig. 1.6. It is necessary to find new products which are not available otherwise by traditional crops or methods. These challenges will resolve the problem of demand and supply and utilize the available biomass, generate new jobs and help in economic upliftment of farmers. The use of solid-state fermentation, development of efficient bacterial and fungal strains and environmentally friendly processes are the need of hour. Proper utilization of available resources will solve many socio-economic as well as environmental problems and help in improving living of people in rural areas particularly in developing countries.

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