Chapter 3

Impact of Climate Change on Nutraceutical Properties of Vegetables

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Abstract Due to the fact that vegetables are the only cheapest source of nutrients, vitamins, and minerals, hence they are a crucial part of the human diet. They provide good remunerative to the growers as they fetch more money from market. The effects of climate change, such as global warming, modifications to seasonal and monsoon patterns, and biotic and abiotic variables, are also having an impact on these crops, just like they do on other crops. Crop failures, low yields, declining quality, and an increase in pest and disease issues are frequent under climate change-related conditions, which make unprofitable to cultivate vegetables. Because of many physiological and enzymatic processes depend on temperature, they will be significantly impacted. The two most significant effects of temperature rise on vegetable cultivation are drought and salt. Crop yields may improve as a result of increased CO_2 fertilisation; however, this positive effect decreases after certain point. Greenhouse gases produced by human activity, such as CO_2, CH_4, and CFCs, are a major factor in global warming, while sulphate and nitrogen dioxides weaken the ozone layer and allow dangerous UV rays to enter the atmosphere. These climate change effects also have severe impact on the prevalence of pests and diseases, as well as on the nutritional value (vitamins, minerals, proteins, etc.) and aesthetics of vegetable crops. Iron and zinc levels, as well as the amount of protein in vegetable crops, were dramatically lowered by higher CO_2 levels. In the end, the quality and volume of global vegetable output are falling due to climate change.

Keywords Vegetables · Climate change · Greenhouse gasses · Nutritional value

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3.1 Introduction

The main cause of abiotic stress in today's vegetable cultivation is climate change. The cropping systems of vegetable should be climate change resistant, so that the vegetable production technology can achieve both economically successful and environmentally sustainable. The productivity of vegetable crop is severely threatened by environmental stresses including flooding, drought, and excessive temperatures which finally results in complete crop failures (Singh et al. 2020). The head of the Foundation for Innovation in Medicine (FIM) and executive Director Dr. Stephen L. De Felice, invented the term "nutraceutical" in 1979 as a combination of the phrases "nutrition" and "pharmaceutical" (Crawford, New Jersey) (Kalra 2003). It is a food item or food-related product that provides both medicinal and health advantages, such as illness prevention and therapy. They are products that have been separated or purified from foods, usually offered in therapeutic forms unrelated to food, and have been shown to provide physiological benefits or offer protection from chronic illness (Singh and Devi 2015). Due to an unbalanced diet, approximately worldwide 3 billion people suffer from malnutrition. A balanced diet must include vegetables because they are an excellent source of nutraceutical substances and phytonutrients. Climate change has a significant negative impact on the production, quality, and productivity of vegetable crops (Kumari et al. 2021). Under adverse environmental stress, such as heat, cold, drought, flood, and salinity, many plant species' genes are activated, enabling them to withstand a variety of stress conditions (Solankey et al. 2021a). Vegetables are recognised as protective foods since they are a great supply of vitamins, minerals, carbs, and proteins. They also offer health protection because of the presence of secondary metabolites with medicinal value. The most prominent phytonutriceuticals in vegetables with biological activity against chronic diseases include vitamins, minerals, dietary fibre, organosulfur compounds (glucosinolates and thiosulfides), and flavonoids. Among all crops, potatoes are particularly sensitive to climate change since they need a certain environment for a number of physiological processes (Singh and Devi 2015). Fighting against hunger and malnutrition are now two main priorities of developing nations. In India, around 43.5% children under the age of 5-year-old are chronically undernourished. Vegetable consumption is usually thought to have a number of beneficial impacts on health. Risk of cancer and other cardiovascular disease are directly linked with low consumption of fruit and vegetables Martinez-Gonzalez et al. (2011); Krebs and Kantor (2001); Lock et al. (2005); and Mosby et al. (2011). Vegetables with a wide variety and high nutritional value are crucial for reducing malnutrition. As mentioned in below Table 3.1, each vegetable includes a distinct combination of phytonutrients.

Vegetables with high amount of anthocyanin (broccoli, black/ purple carrot, purple brinjal and purple cauliflower) are becoming more or more popular day-by-day due to their increased activity of antioxidant (Table 3.2). The colour features of radish and potato extracts are quite comparable to those of Allura red (Shipp and Abdel 2010).

Table 3.1 Biochemical compound that have nutritional importance found in vegetables

Nutraceuticals	Vegetables
Glucosinolates, Sulforaphane	Cole crops
Lycopene	*Solanum lycopersicum* & various Nightshade family crops, *Citrullus lanatus*
Silymarin	*Cynara cardunculus* var. *scolymus*
Ascorbic acid	*Brassica oleracea* var. *capitata*, *Brassica oleracea* var. *italica*, green leafy vegetables
Tocopherol	Green leafy vegetables
Allyl sulphides	Alliaceae family crops
Retinol	*Daucus carota*, *Cucurbita moschata*, *Cucumis melo* var. *cantalupensis*
Ascorbic acid	*Momordica charantia*, *Capsicum annuum* var. *grossum*
Folates	Green leafy vegetables
Alliin, Methiin	*Allium species*
Quercetin	*Allium cepa* & *Allium sativum*
Kaempferol, Myricetin, Fisetin	*Allium cepa*, *Lactuca sativa*, endive, *Armoracia rusticana*
Luteolin	*Apium graveolens*, *Brassica oleracea* var. *italica*
Apigenin	*Apium graveolens*, *Brassica oleracea* var. *capitata* and *Lactuca sativa*
Isoflavonoids	Legume vegetables, *Brassica oleracea* var. *italica* and *Abelmoschus esculentus*
Genistein and Daidzein	*Glycine max*
Glucoraphanin	*Brassica oleracea* var. *capitata* f. *rubra* and *Brassica oleracea* var. *italica*
Glucobrassicin, Progoitrin, Gluconasturtiin	*Brassica oleracea* var. *italica*
Glucoerucin, glucoraphanin	*Brassica rapa* and *Brassica napus* var. *napobrassica*
Lysine, Chlorgenic acid	*Solanum tuberosum*
Caffeic acid, Chlorgenic acid	*Solanum melongena*
Nasunin	*Solanum melongena*
Angelicin, Xanthotoxin	*Pastinaca sativa*
Ferulic acid, Betanin	*Beta vulgaris*
Anthocyanin and Chlorgenic acid	*Ipomoea batatas*
Rutin	*Asparagus officinalis, Capsicum annuum* (green color)
Patuletin, Spinacetin	*Spinacea oleracea*
2″-xyloside vitexin and 6″-malonyl-2″-xyloside vitexin	Swiss Chard
Betanin	*Beta vulgaris*
Capsaicin	*Capsicum annuum* (red color)
Carnitine	*Asparagus officinalis*
Curcumin	*Curcuma longa*
Hesperitin	Green leafy vegetables
Lignan	*Glycine max* and *Brassica oleracea* var. *italica*
Resveratol	*Allium cepa* (red)

Adapted from Singh and Devi (2015)

Table 3.2 Anthocyanin concentration in different vegetables

Vegetable	Anthocyanin (mg/100 g)	References
Brassica oleracea var. *capitata* f. *rubra*	322	Wu et al. (2006)
Raphanus sativus (red)	100–154	Wu et al. (2006)
Allium cepa (red)	23.3–48.5	Ferreres et al. (1996)
Solanum melongena	8–85	Koponen et al. (2007)

Adapted from Singh and Devi (2015)

3.2 Improvement of Nutrition in Vegetables

As we go into the twenty-first century, improving the nutritional quality of horticulture products, particularly the nutraceutical importance of green veggies will make plant breeder's efforts profitable. It is becoming increasingly clear that eating healthful meals may help maintain a healthy lifestyle and that eating is not only for body growth and subsistence in industrialised nations when the majority of the population has access to enough food. People are starting to eat more nutritious foods that can help with "diseases of excess" and chronic diseases linked to diet, such some forms of obesity, heart disease, and some types of cancer. Along with other agricultural professionals and extension agents, plant breeder's services, are primarily responsible for the world's population's access to an abundance of food, better health and nutrition, and stunning landscapes. Breeding plants to increase their mineral and vitamin content has a number of beneficial advantages. The majority of breeding and genetic work has been focused on crops like *Daucus carota*, *Ipomoea batatas*, *Capsicum annuum*, *Solanum lycopersicon*, *Cucurbita moschata, and Cucumis sp.* that are already reasonably rich suppliers of vitamins (Singh and Devi 2015). In Tomato, dominant gene (Aft) Anthocyanin fruit responsible for purple colour, which generates restricted pigmentation upon stimulation by high light intensity was introduced into tomato by crossing domestic tomato plants with *S. chilense* (Mes et al. 2008; Jones et al. 2003). A robust and varied pigmentation may also be induced in the tomato peel from *Solanum lycopersicoides* Dunal by the gene Aubergine (Abg). Red cabbage's anthocyanin production and accumulation are mediated by the transcriptional activation of the anthocyanin structural genes by the bHLH and MYB transcription factors (Yuan et al. 2009).

An intriguing genetic mutation known as spontaneous reported in Cauliflower (*Brassica oleracea* var. *botrytis*) which is responsible for semi dominant Orange (Or) mutant that causes carotenoid deposition in typically unpigmented tissues (Dickson et al. 1998). The Or gene causes the plant‘s tissues to accumulate large quantities of β-carotene, which is responsible for orange colour. This is especially noticeable in the plants with white edible curd and shoot apical meristem. Mano et al. (2007) reported the finding of a new R2R3-type MYB gene, IbMYB1, and its predominant expression in the root of tuberous vegetable of purple-fleshed cultivars using a purple-fleshed sweet potato cDNA library. Purple colour of *Ipomoea batatas* tuberous roots in the flesh is caused by the gene IbMYB1. A ripening-inducible E8 promoter and a yeast S-adenosylmethionine decarboxylase gene (ySAMdc;

Spe2) in tomato fruit were coupled to raise the polyamines spermidine and spermine levels. By increasing the conversion of putrescine into higher polyamines, the ySAMdc gene promoted spermidine and spermine, which are ripening-specific compound. According to these results, the overall quality of fruit juice was improved due to increase in lycopene and shelf life of vine. Since cultivated tomatoes contain generally low amounts of lycopene and raising lycopene levels will improve the fruit's nutritional value. Romer et al. (2000) boost the carotenoid content and profile of tomato fruit, trans-genic lines have been created that express the bacterial carotenoid gene (crtI), which makes the enzyme phytoene desaturase, which converts phytoene into lycopene. However, the amount of β -carotene more than tripled, reaching 45% of the total carotenoid content. Chromosome fragments of *Brassica villosa*, a wild progenitor has been introgressed to increase the amount of glucosinolates. Depending on the *B. villosa* allele, indole-3-carbinol or sulphoraphane is produced during hydrolysis. *Brassica rapa* is a root vegetable that is most often consumed in Asia. As compared to *B. oleracea, B. rapa* contain different types of isothiocynates and a new research shows that it also gives protective benefits to people who lack GSTM1 (Gasper et al. 2005). Table 3.3 list of gene which is responsible for enhancing various nutraceutical components in various vegetables.

3.3 Quality of Vegetables/Fruits and Elevated CO_2

Additionally, it has been noted that in various vegetables, increased CO_2 raises the concentrations of some bioactive substances. The impact of elevated CO_2 on physiology of vegetables/fruits have been summarised by Moretti et al. 2010. In their research, it was found that several vegetables/fruits had reduced alkaloids and organic acids while increased ascorbic acid, flavonoids, sugars, phenols, starch anthocyanin and also firmness and colour (Shivashankara et al. 2013). According to Zhang et al. (2014), tomato fruits with increased CO_2 had significantly higher concentrations of compounds like Vitamin A, lycopene, Vitamin C, which are essential for development of our health and also had high amount of chemicals like titrable acidity, total soluble solids and sugar/acid ratio which is known as flavor-enhancing chemicals. The tomato fruit firmness, colour, fragrance, and sensory qualities were also markedly improved by CO_2 enrichment. Yield contributing characters like fruits per plant and average weight of fruits were main contributing characters for yield n tomato under heat stress (Solankey et al. 2017).

3.4 Vitamin C, Sugars and Acidity

Protective antioxidant substances like ascorbate and phenolics are created by plants by extra carbon which is fixed during enrichment of CO_2. In Tomato fruits, when enhanced CO_2 was provided at various degrees of maturity, some quality metrics

Table 3.3 Vegetable gene list responsible for nutraceutical enhancement

Vegetable crop	Gene	Nutrient enhancement
Solanum tuberosum	*Or*	β-carotene
Brassica oleracea var. *botrytis*	*Or*	β-carotene
Solanum tuberosum	*AmA1*	Protein
Solanum tuberosum	*Crt B*	β-carotene
Solanum lycopersicum	*B*	β-carotene
Ipomoea batatas	*asp-1*	High protein
Solanum lycopersicum	*Phytoene synthase − 1(Psy-1)*	Carotenoids
Solanum lycopersicum	*chi-a*	High flavonols
Solanum lycopersicum	*LC and C1*	Kaempferol
Solanum lycopersicum	*Aft, Abg*	Anthocyanin
Cucumis sativus	*Ore*	β-carotene
Brassica oleracea var. *capitata* f. *rubra*	*MYB*	Anthocyanin
Brassica oleracea var. *botrytis* (purple)	*Pr*	Anthocyanin
Ipomoea batatas	*IbMYB1*	Anthocyanin
Solanum lycopersicum	*Cry-2*	Lutein
Solanum lycopersicum	*ySAMdc; Spe2*	Lycopene
Solanum tuberosum	*Dxs*	Phytoene
Solanum lycopersicum	*GCH1*	Folate
Lactuca sativa	*Gch1*	Folate
Lactuca sativa	*Pfe*	Iron
Lactuca sativa	*Gul oxidase*	Ascorbate
Solanum lycopersicum	*hmgr-1*	Tocopherols

Adapted from Singh and Devi (2015)

like organic acids were lower whereas, ascorbic acid and sugars were maximum (Islam et al. 1996). The increased CO_2 improved fruit colour and development. In tomato at the pink stage, acidity and ascorbic acid levels are maximum whereas, slightly going down during ripening stage. In bean sprouts, ascorbic acid levels were also found to increase by two folds even with a CO_2 concentration that was doubled for 1 h each day for 7 days (Tajiri 1985). High CO_2 increased total sugars and acidity in grapes, although the impact was only noticeable during middle stage of ripening (Kurooka et al. 1990 and Bindi et al. 2001).

3.5 Total Phenols, Anthocyanins and Flavonoids

Under high CO_2 concentrations, tomato antioxidant levels increased at very slow rate (Barbale 1970; Madsen 1971, 1975; Kimball and Mitchell 1981).

3.6 Volatile Aroma Compounds

In field-grown strawberries (*Fragaria ananassa* Duch), Wang and Bunce (2004) examined how elevated CO_2 affected the volatile aroma composition and fruit quality. Under high CO_2 levels, ethyl hexanoate, ethyl butanoate, methyl hexanoate, methyl butanoate, hexyl acetate, hexyl hexanoate, furaneol, linalool, and methyl octanoate content of these key strawberry scent esters increased significantly (Shivashankara et al. 2013).

3.7 Mineral Nutrients

It has been suggested that increased CO_2 has an impact on nutrients supply of vegetable and fruits. Lettuce produced in high CO_2 environments reported lower ash content (McKeehen et al. 1996). In a number of types of woody and herbaceous plants, significant reductions in minerals including Iron, nitogen, sulphur, Magnesium, Calcium, Zinc (15–25%) were observed when CO_2 levels were high (Loladze 2002). Chronic exposure to high CO_2 levels may also have an impact on product quality (Gruda 2005), with total soluble solids, Vitamin C and capacity of antioxidant being enriched, while other macronutrients and micronutrients in green vegetables, such magnesium, iron, and zinc, may be depleted (Dong et al. 2018).

3.8 Effect of High Temperature on Quality

Heat waves may significantly affect plant growth, production, and product quality in horticulture. Open field crops are extensively exposed to sunlight and high temperatures during heat waves. Physiological problems associated with calcium (Ca) uptake are frequently brought on by a lack of protection against stress. Plants transpire a lot of water when it's hot outdoors, which causes all the calcium in the transpiration stream to flow directly to the leaves (Bisbis et al. 2019). Since Ca doesn't reach the developing tip and the enclosing leaves in lettuce, this commonly results in tip burn, which results in necrosis on the margins of new leaves (Collier and Tibbitts 1982). Low transpiration results in insufficient Ca being allocated to the fruits, which results in blossom end rot in fruiting plants like tomato or pepper. Under the influence of global warming, winter dormancy may be hindered, which may have an impact on the output of perennial vegetables. For instance, during the cold season, asparagus becomes dormant and accumulates frigid temperatures of 0–7 °C (Nie et al. 2016). Since cauliflower starts curd formation only at a temperature of 7–10 °C, therefore, higher temperatures might delay the process. When the temperature was increased by 2.9 °C above ambient the head development took place 49 days later in cauliflower (Wurr et al. 1996). Heat stress alters the physical characteristics of biomolecules directly (Solankey et al. 2021b).

In an experiment with broccoli, Kaluzewicz et al. (2009) found that the higher the temperature was maintained for longer periods of time throughout the initial phase of growth that occurs after sowing as well as the period just before harvest, the greater the yield. If broccoli heads were exposed over 20 °C temperature for a longer period then the resulting yields were lower**.** The proportion of broccoli heads with an uneven surface decrease with the amount of time spent at temperatures between 5 and 15 °C during harvest and between 20 and 25 °C during the growth period before harvest. At the time of harvest, if broccoli heads exposed over 20 °C temperatures for a longer time results in development of loose heads.

3.9 Vitamin C, Sugars and Acidity

The healthy growth and development of plants, as well as the determination of the phonological phases, depend greatly on temperature. Among various fruit crops *Vitis venifera* are the most significant which are impacted by high temperatures for prolonged periods of time. In Tomato, due to high temperature biochemical compounds like sugar, acidity and dry weight are reduced (Bikash Khanal 2012).

3.10 Phenols, Flavonoids and Anthocyanins

Increases in temperature hinder the colour development. The anthocyanin concentration is more sensitive to night temperatures than to day temperatures (Mori et al. 2005). The polyphenol content of several tomato varieties ranged from 104 to 400 mg kg^{-1}, according to George et al. (2004). This behaviour may be viewed as the plant‘s acclimatisation to heat stress (Rivero et al. 2001). Fruits lose some of their antioxidant capacity at lower temperatures (Wang and Zheng 2001). Even at 25 °C temperatures, heat in broccoli can result in diseases and deformities such as uneven heads and oversized flower buds (Kaluzewicz et al. 2009). Heat triggered bracting in sensitive cultivars during this stage of head development (Wiebe 1972), and harvest temperatures exceeding 25 °C caused loose heads and early ripening (Kaluzewicz et al. 2009). High temperatures also resulted in uneven and less sweet heads, but they also raised the flavonol content and changed the composition of the glucosinolates in the florets (Molmann et al. 2015).

3.11 Lycopene and Carotenoids Content

High temperatures typically result in smaller size of tomato fruit and higher dry matter content. Lycopene content is also impacted by the high day/night temperature treatments (30°/25 °C) in tomato (*Lycopersicon esculentum* Mill., cv. “Laura”) compared to the control temperature (28°/23 °C) (Fleisher et al. 2006). The amount of lycopene and other nutritional value components in tomatoes are further diminished by high sun radiation and temperature (Dumas et al. 2003; Helyes et al. 2003; Rosales et al. 2006). It has been shown that beyond 40 °C, ß-carotene content and synthesis decreases (Gautier et al. 2005). The quality of the fruit is greatly influenced by the high temperature caused by direct solar exposure rather than plant temperature due to lycopene degradation. Instead of plant temperature, direct solar radiation-induced high temperature on the fruit surface has a significant impact on the fruit's quality because lycopene is degradable (Dumas et al. 2003). As a result, tomato fruits produced in greenhouses have 40% more lycopene than tomatoes grown in fields as a result (Helyes et al. 2007).

3.12 Terpenoids

High temperatures change the volatile fragrance molecules in many vegetables in addition to the bioactive components. The effect of high temperature on the soybean isoflavone quality was observed to fluctuate with increased CO_2 and water stress (Caldwell et al. 2005).

3.13 Stress from Water's Impact

The disruptions in Ca allocation brought on by heat are not the sole factor contributing to lettuce tip burn; Ca absorption is also a factor. Poor Ca absorption may also result from insufficient soil water uptake (Bisbis et al. 2019). Additionally, too much water may result in buttoning, nitrate leaching, and a consequent decrease in output because the soil is depleted of nutrients (Kaiser et al. 2011). The flowering stalk's elongation from the core causes bolting, which happens in lettuce right before bloom induction (Kumar et al. 2012; Chatterjee and Solankey 2015). Bolting in lettuce causes bitterer leaves and worse head development, which are undesirable in all except stem lettuce. High temperatures might also cause premature bolting (Simko and Hayes 2015).

3.14 Sugars, Ascorbic Acid and Acidity

Stress of water makes fruits less juicy, which raises their sugar content (Chartzoulakis et al. 1999). The consequences, however, depends mostly on the phenological stage of water stress and may render fruits utterly non-commercial (Romero et al. 2006). By applying the treatment at later phases of fruit maturity, deficit irrigation therapy is utilised in some fruit crops to boost the sugar content. Under deficit irrigation circumstances, tomato showed higher total soluble solids and sugars (Mitchell et al. 1991; Birhanu and Tilahun 2010). However, water stress causes a drop in tomato marketable yield.

3.15 Phenols, Flavonoids and Anthocyanins

Strawberries accumulated more proanthocyanidins and anthocyanins due to inadequate watering. The increased activity of phenylalanine ammonia-lyase under water scarcity condition is primarily responsible for the increase in anthocyanins and phenolic compounds (Tovar et al. 2002). Mineral movement like nitrogen, potassium and phosphorus within the tree is going to be affected by the water stress. However, lack of water has a negative impact on the quality during fruit set and the early stages of fruit growth. The water stress affects the impact of transport of minerals like nitrogen, potassium, and phosphorus inside the tree (Kirnak et al. 2001). If this happens during the active period of fruit growth will have an impact on the quality of the fruit.

3.16 Lycopene and Carotenoids

The primary pigments in many fruits and vegetables are due to carotenoids, which is isoprenoids that are naturally occurring and have antioxidant characteristics.

3.17 Salinity Stress

One of the key environmental conditions that inhibits plant development, yield, and output is salt stress. It has been discovered that salt stress during fruit development stage limits the vegetative growth and fruit quality (Shivashankara et al. 2013).

3.18 Phenols, Flavonoids and Anthocyanins

Reactive oxygen species (ROS) and their scavengers, enzymes, or nonenzymatic low molecular mass antioxidants are known to arise in response to salt stress.

3.19 Lycopene and Carotenoids

Antioxidants like lycopene, carotenoids and ascorbic acid accumulated in tomato fruits during salt stress. Reactive oxygen species (ROS) and their scavengers, enzymes, or nonenzymatic low molecular mass antioxidants are known to arise in response to salt stress (D'Amico et al. 2003). However, under salt stress, the leaves of *Solanum lycopersicum* plant exhibit a reduced expression of carotenoid biosynthesis genes, which significantly slows down photosynthesis and lowers plant productivity and yield (Merlene et al. 2011). Abiotic stressors have a significant impact on the antioxidant capacity of fruits.

3.20 Conclusion

Regular eating of a diet high in vegetables has undeniably beneficial benefits on health since the phytonutrients in vegetables can shield the body against many chronic illnesses. Cruciferous vegetables, bulb crops, tomatoes, cucurbits, soybeans, carrots, okra, and underutilised vegetables including lettuce, coleus, sweet potatoes, yams, moringa, winged beans, basella, horse purslane, and cluster beans are rich sources of bioactive chemicals. Abiotic stress effects on antioxidant quality are further amplified by climate change. Adaptation tactics, including as the cultivation of robust crop varieties, effective irrigation systems, unique pollination techniques, and agricultural technologies, will be needed to adjust to changing environmental circumstances and preserve the supply of foods that are crucial for human sustenance. As a result, efforts must be made to comprehend the impact of various abiotic stresses on various fruit crops as well as the critical stages of fruit growth at which the overall quality of the vegetables are adversely affected. Additionally, strategies must be developed to counteract the negative effects of abiotic stresses.

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