Chapter 5
Impact of Climate Change on Leafy and Salad Vegetables Production

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Abstract Due to their significant nutrient, vitamin, and mineral content, leafy vegetables are an essential part of the human diet. In addition to other vegetable crops, these are also being impacted by the effects of climate change, such as global warming, changes to the seasonal and monsoon patterns, and biotic and abiotic factors. Crop failures, low yields, declining quality, and an increase in pest and disease issues are frequent in climatically changing regions, making it unprofitable to grow leafy and salad vegetables. They will be significantly impacted because many physiological processes and enzymatic activities depend on temperature. The two main effects of temperature rise that make vegetable cultivation more difficult are drought and salinity. Crop yields may increase as a result of increased CO_2 fertilization, but this effect only lasts to a certain point. These effects of climate change also have an impact on the occurrence of pests and diseases, host-pathogen interactions, insect distribution and ecology, timing of appearance, migration to new locations, and their capacity for overwintering, which is a significant hindrance to the cultivation of leafy vegetables. Therefore, appropriate preventive measures must be taken as soon as possible to lessen the aforementioned challenges.

Keywords Global warming · Leafy vegetables · Amaranthus · Spinach · Salad vegetable · Lettuce

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5.1 Introduction

Due to the alarming rate of increase in industrialization and deforestation, catastrophic changes have occurred in the global climatic conditions (Rakshit et al. 2009). The changes in climate refer to fluctuations in temperature, increases in soil salinity, water logging, increased CO_2 content, and UV radiation. High temperature is the result of increased greenhouse gases such as carbon dioxide and methane. This rise in temperature leads to extreme weather conditions including droughts, heat waves, floods, or storms, changes in ocean currents, and hastens the rate of ozone depletion (Minaxi et al. 2011; Usman and Balsalobre-Lorente 2022; Murshed et al. 2022; Kumar 2012). An increase in temperature also leads to the melting of glaciers, ultimately leading torising sea levels causing flooding and an increased level of salinity in small Pacific states and low-lying countries. Agriculture in India mostly depends upon the climatic condition of a region. The Indira Gandhi Institute of Development Research has found that global warming may lead to a decline in India's GDP by upto 9% (Priyadarshini and Abhilash 2019). Changes in climate raise the risk of particular food, water, and vector-borne diseases; a coronavirus pandemic is a visible example (Abbass et al. 2022). Increased rates of malnutrition, poor health, hunger, starvation, and food and water insecurity are all indirectly correlated with climate change. Thus, a solution is one suggestion to resolve global issues, and be taken into account that gives equal weight to human nutrition, health, (Sarker et al. 2022).

Leafy vegetables embedded with mineral matter, phytochemicals, and provitamin must be in a substantial proportion for a balanced diet (Adenipekun and Oyetunji 2010). Dieticians recommend daily consumption of at least 116 g of leafy vegetables for a balanced diet. Leafy vegetables are also good sources of fibre, which helps in the functioning of the digestive system. Consuming plenty of leafy vegetables assists in protection against bowl cancer which is one of the most common cancers. There is a wide variation in the consumption of leafy vegetables in different parts of the world. Due to wide variation in the climate of the country, various types of wild herbaceous/perennials are consumed by local people. In this chapter, relationships between the production of leafy vegetables and environmental factors namely temperature, light, soil, and water have been discussed.

5.2 Importance of Leafy Vegetables and Salad Crops

Leafy vegetables serve as essential sources of protective foods (Nnamani et al. 2009). The bioactive compounds present in the leafy vegetables possess numerous antimicrobial and antioxidant properties (Kim et al. 2013) and are recommended for controlling and managing age-related ailments and oxidative strains (Gacch et al. 2010). Leafy vegetables are rich sources of minerals (Fe, P, and Ca), vitamin C, Vitamin E, carotenoids, and flavonoids (Fasuyi 2006). Owing to the high accumulation of photosynthates, a significant amount of Potassium can be availed in leafy vegetables as Potassium is directly involved in the photosynthesis process. Besides, leafy salad vegetables synthesize a number of secondary metabolites, which act as antimicrobial agents. They also possess antidiabetic (Kesari et al. 2005), antihistaminic (Yamamura et al. 1998), anticarcinogenic (Rajeshkumar et al. 2002), and hypolipidemic (Khanna et al. 2002) properties.

Besides the major constituents of food (carbohydrate, protein, and fat) and micronutrients (minerals, vitamins, and trace elements), many health-promoting substances such as flavonoids, carotenoids, and other polyphenols, allylic sulfides, monoterpenes dietary fibers, phytosterols, and phenolic acids (Kris-Etherton et al. 2002) are also present in the leafy vegetables. Gupta et al. (2005) found the leafy vegetables to possess some antinutritional compounds such as saponins having the potential to reduce diseases like high blood pressure, heart disease, stroke, and other cardio vascular diseases in human beings (Williamson et al. 1997). The fibre present in the leafy vegetables assists to reduce the intake of starchy food, constipation prevention, and reducing the incidence of metabolic diseases such as hypercholesterolemia and *Diabetes mellitus*. Leafy Vegetables as soup are reported to enhance fertility in females (Mensah et al. 2008). Also, growing these alternative vegetables will improve both human health and the income of farmers in poor nations. (Sarker et al. 2022).

5.3 Factors Responsible for Climate Change on Leafy and Salad Vegetable Production

5.3.1 Temperature

Temperature variation within seasons is a sign of global warming as a result of climate change (Solankey et al. 2021). Among climatic factors influencing vegetable production, the temperature is the most important component. Temperature influences the yield, quality, and shelf life of produce, seed production, bud and seed dormancy, viability and longevity of seed and the occurrence of insects-pests and diseases.

5.3.1.1 Effects of Temperature on Seed Germination

Optimum growth of most of vegetables occurs between 10 °C and 30 °C, but when the temperature goes above 30 °C or falls below 10 °C, a decrease in plant vigor and growth is observed, due to the discrepancy in the rate of metabolic pathways (Downs and Hellermers 1975). Seed germination in leafy vegetables like amaranthus is significantly affected by temperature. The optimum temperature for germination in amaranthus is observed to be between 15 °C to 40 °C, while the optimum temperature is 25 °C. However, when the temperature falls below 10 °C, no seed germination is observed (Tiryaki 2009). Hence, in cold areas, where the soil temperature is the major hindrance, increasing the media temperature and the provision of dark conditions during sowing has been successful in enhancing the germination percentage in amaranthus (Aufhammer et al. 1998; Loonat et al. 2003). Similarly, in crops like lettuce exhibiting thermo-dormancy, high temperature (more than 30 °C) due to climate change has been a major challenge (Berrie 1966; Reynolds and Thompson 1971). Besides cool season leafy vegetables, tropical leafy vegetable such as drumstick (*Moringa oleifera*) is vastly affected by high temperature. 20/30 °C temperature regime (TR) leads to a significant enhancement in germination rate as well as uniformity (Muhl et al. 2011). However, as the temperature increases, a gradual decline can be observed in germination in drumsticks.

Germination and initial establishment of seedlings of Spinach (*Spinacia oleracea* L.) are highly susceptible to chilling and freezing injury, heat, and moisture stress (Ashraf and Foolad 2005). For optimal germination success, pericarp removal through mechanical means is recommended, however, when the temperature exceeds 25 °C, a significant reduction in germination percentage was observed (Atherton and Farooque 1983). The germination of seeds of spinach is found to be restricted when the temperature 35 °C (Leskovar et al. 1999). In a germination study, carried out by Katzman et al. (2001) on spinach, the results showed that the maximum germination in spinach can be achieved at 18 °C.

5.3.1.2 Effect of Temperature on Growth and Development

The optimum temperature is that at which the photosynthetic rate is highest with normal respiration rate or which the net assimilation rate (NAR) and yield realization are highest. During the daytime, the plants synthesize carbohydrates and simultaneously utilize in respiration. At high day temperatures, rate of respiration will be very high resulting in low net photosynthesis. Net photosynthesis refers to the amount of carbohydrates synthesized by the plant minus the amount of carbohydrates utilized in respiration in a specific period. Net photosynthesis, thus, determines the amount of carbohydrates available for growth of plant during the following night.

Warm season leafy vegetables like amaranthus requires a temperature in the range of 25–30 °C for the maximum accumulation of biomass (Khandaker et al. 2010). Similarly, in intensive care requiring crops like lettuce both ambient temperature as well as root zone temperature play key role in obtaining maximum leaf yield. An ambient temperature of 19–24 °C leads to the maximum plant growth (Lafta et al. 2017; Chen et al. 2021). However, low root zone temperature leads to the reduction of leaf area, fresh weight, stem size, and water content of lettuce (Sakamoto and Suzuki 2015). Yield and quality of lettuce are drastically affected by higher temperature due to abnormal acceleration in the elongation of lettuce stems (Zhao et al. 2003; Rader and Karlsson 2006). High temperature orchestrated stem elongation leads to the formation of loose heads, ultimately becoming unmarketable (Jie and Kong 1998).

5.3.1.3 On Nutritional Properties of Leaves

Leafy vegetables are mostly consumed owing to their nutritional properties, which are significantly affected by fluctuating temperatures. The major pigment with high nutritional value in amaranthus is anthocyanin, especially betacyanin in the case of red amaranthus. The mean optimum temperature for the highest accumulation of betacyanin content has been recorded to be 28–29 °C (Khandaker et al. 2010). In the presence of high temperature, red coloration with enhanced color index can be achieved in red amaranth. Beta-carotene and lutein are among the most important pigments in vegetable crops broadly available in kale and spinach. Research shows the maximum accumulation of beta-carotene and lutein occurs at 30 °C and 10 °C for kale and spinach, respectively. Lutein and beta carotene concentration are positively associated with an increase in temperature for kale and negatively associated with increasing temperature in the case of spinach (Lefsrud et al. 2005). As evidenced by numerous researchers, spinach is one of the best sources of ascorbic acid, oxalic acid, and sugar. These compounds are also significantly affected by the temperature regime of the growing environment. The low temperature of 5–10 °C during growing conditions is found to be the optimum temperature for ascorbic acid, oxalic acid, and sugar accumulation in spinach leaves (Tamura 2004; Proietti et al. 2009). Sugar and ascorbic acid content are found to increase rapidly when the minimum air temperature decreases below 5 °C (Tamura 2004). In coriander, besides ambient temperature, root zone temperature plays a key role in enhancing the secondary metabolite content. The secondary metabolites such as ascorbic acid, carotenoids, phenolic compounds, and chlorogenic acid content of the coriander leaves increase substantially the root zone temperature by 15–35 °C (Nguyen et al. 2020). In lettuce and Japanese parsley (*Oenanthe stolonifera*), the accumulation of the health-promoting pigments such as anthocyanin and chlorophyll b in leaves is the highest at the low temperature of 20 °C (Hasegawa et al. 2001; Gazula et al. 2005).

5.3.1.4 Effect of Temperature on Quality of Produce

In most of the leafy and salad vegetables, the quality of produce is usually influenced by temperature. It affects the quality of produces not only by increasing respiration and transpiration but also by damaging the tissues or altering morphology following exposure to excessive heat or chilling by bringing changes in relative amounts of sugar and starch of edible parts.

Temperature can be regarded as the only factor governing the post-harvest quality of leafy vegetables. Generally, a combination of high humidity and low temperature significantly enhances the self-life of most of leafy vegetables (Cantwell and Kasmire 2002), due to delayed chlorophyll degradation (Pogson and Morris 1997) owing to the high transpiration rate, as leafy vegetables have more exposed surface area. Hence, accelerated loss of color and senescence is a major issue if plants get exposed to high temperatures.

5.3.1.5 On Disease Development

High temperature and High humidity both favor the development of foliage diseases and pests' population. Pathogens like *Rhizoctonia solani* and *Sclerotini asclerotiorum* in lettuce have more devastating effects on plants in the presence of high temperatures (Grosch and Kofoet 2003; Clarkson et al. 2014). Similarly, one of the major soil-borne pathogens *Fusarium oxysporumf.sp. lactucae* infestation in lettuce increases rapidly with an increase in temperature (Ferrocino et al. 2013). Similarly, in spinach, rust and anthracnose are the two major diseases diminishing the market value significantly. A high temperature of 15–18 °C leads to a significant increase in rust infection, while more than 20 °C results in severe anthracnose infestation in spinach (Sullivan et al. 2002; Uysal and Kurt 2017). A similar negative impact of high temperature can also be observed in parsley for septoria blight diseases. When ambient temperature increases from 20 °C to 30 °C, an increase in the mean lesion number is observed (Kurt and Tok 2005).

5.3.1.6 Effect of Temperature on Physiological Disorders

Temperature is the most important component actively influencing the growth and development of leafy vegetables and salad crops up to varying extents (Table 5.1). For example, high temperature for a short period of time leads to accelerated growth, however prolonged exposure causes tip burn and bolting in lettuce (Cox et al. 1976;

Table 5.1 Classification of leafy vegetables and salad crops based on reaction to high temperature

Degree of sensitivity	Vegetables	Effect due to prolong period
Sensitive	Parsnip	Inferior root quality
	Lettuce	Bolting, loose heads, bitterness, tip burn, small & light heads, thermo-dormancy od seeds, Ca deficiency
	Celery	Less quality stems
Moderate sensitive	Spinach	Reduced yields
Tolerant	Shallot	Tolerant
	Basella	Tolerant
	Parsley	Tolerant
	Amaranthus	Tolerant
Highly tolerant	Malabar Spinach	Highly tolerant
	New Zealand Spinach	Highly tolerant

Fukuda et al. 2009). High temperature during growing conditions even for 2 weeks can lead to discoloration of ribs in lettuce (Jenni 2005).

The bitterness of the leaves is observed in lettuce upon prolonged exposure to high temperatures. Spinach beet can tolerate frost better than other vegetables. It can also tolerate warm weather but high temperature leads to premature bolting without giving economic yield. Palak can tolerate high temperatures, unlike spinach which is purely a cool-season crop. It fits well in different crop rotations due to its adaptation to high temperatures condition, short cropping duration, and appreciable biomass yield per unit area. Amaranthus although being considered a warm season crop can also be grown successfully in temperate climate during summer. *Amaranthus* species that grow under varying climatic conditions differ in their day length requirements and respond differently to changes in photo and thermoperiodism.

However, in temperature fluctuation area, some varieties of the mentioned leafy vegetable and salad crops can be grown successfully (Table 5.2).

5.3.2 Light

The biochemical processes that take place in plants in the presence of light produces carbohydrates and chemical energy. Plants require a greater amount of light, which furnishes energy for the combination of carbon dioxide and water to form first manufactured compound i.e., glucose ($C_6H_{12}O_6$) is necessary for survival, growth, and development of plant. Therefore, greater the amount of light, the greater the photosynthesis and accumulation of carbohydrates in plant body. Several components of light requirement such as light intensity, light source, color of light plays active role in plant growth of leafy vegetables. Light intensity in a range of 200–600 μmol m^{-2} s^{-1} is found to be the most suitable for high light use efficiency and yield in lettuce (Fu et al. 2012). High light intensity leads to low light use efficiency and yield. Similar results such as reduced vigor, leaf area as well as shoot: root ratio and increased amount of oxalate and nitrate are observed in spinach when plants are exposed to relatively low light intensities (Proietti et al. 2004). Besides, yield and yield

Table 5.2 Recommended cultivars to grow in high and low temperature areas

Vegetable	Recommended cultivars
Lettuce	Skyphos, Forlina, Green Butter, Red Butter, Salanova (Butterhead type), Starfighter (Leaf type), Arroyo and Dove (Romain type), Cultivars 9547 and 9542, Salma (a new summer-autumn lettuce cultivar), Elisa (lettuce cultivar for summer cultivation), Florida Butter crisp, Glacier and Misty Dat, Great Lakes (Slow bolting type)
Palak	**Ooty-1 (Drought and frost), Punjab Green, Pusa Harit, New Zealand spinach**
Amaranthus	Chhoti Chaulai (early summer and rainy), Badi Chaulai (summer season), Pusa Kiran (rainy season), Pusa Lal Chaulai: (summer and rainy seasons)
Celery	Sac yuquin

attributing traits, nutritional qualities of leafy vegetables are also affected by light intensity. Optimum light intensity provisions lead to of a greater amount of simple sugars and carotenoid pigments, while in the absence of light, ascorbic acid content reduces at a significant rate in leafy vegetables like chinese kale (Noichinda et al. 2007).

Besides light intensity, supplemental light sources have a significant effect on growth and nutritional properties of leafy vegetables. Supplemental UV-A and blue light results in significant increase in the concentration of anthocyanin pigments. Supplemental red light results in enhancement in phenolics content, while supplemental far red light enhances the fresh weight, dry weight, stem length, leaf length, and leaf width in lettuce (Li et al. 2009). Similarly, white and/or red fluorescent lamps with a photosynthetic photon flux of 300 μmol m^{-2} s^{-1} leads to the accumulation of biomass, β-carotene, and lutein content in spinach. Another source of light such as light-emitting diodes (LEDs) can be used to decrease the bitter component 'gluconapin' and increase in 'glucoraphanin' content in roots, total phenolic, and anthocyanins, as well as the strongest antioxidant capacity of leafy vegetable crops like chinese kale (Qian et al. 2016). Similarly, RGB LED light exhibits the maximum amount of chlorophylls, β-carotene, lutein, neoxanthin and violaxanthin, while plants grown in incandescent light results in the maximum protein content and total thiocyanates content in kale (Fiutak and Michalczyk 2020).

5.3.3 Effect of CO_2

CO_2 plays a major role in the global warming which is predicted to keep rising at an alarming rate to dangerous levels in the coming decades. Several experiments have been carried out to figure out the possible potential of elevated CO_2 to affect crop growth and production potential (Zhang et al. 2015). The elevated CO_2 was found to enhance yield and accumulation of biomass due to the increased rate of photosynthesis (Ainsworth et al. 2002; Prior et al. 2011). The elevated CO_2 also possess the potential to reduce the stomatal conductance of plant which ultimately leads to reduction of transpiration, enhancement in water use efficiency which help plant to combat drought stress (Radoglou and Jarvis 1992). Nonetheless, increase in CO_2 content leads to the reduction in nutritional quality and growth characteristics of lettuce and spinach (Giri et al. 2016). CO_2 concentration has also been found to inhibit disease infestation in leafy vegetable crops. Fusarium wilt of lettuce was found to be inhibited at 800 ppm CO_2 concentration as put forth by Ferrocino et al. (2013).

5.3.4 Rainfall

Rainfall is one of the most important factors, especially when vegetables are grown under dry land conditions, however, high rainfall may cause flood damage, partial drowning on certain soil types, and will often favour disease development. The pattern of rainfall in the region should be studied before taking any decision concerning the types of crop to be cultivated. Local variations in rainfall can influence the methods of cultivation to be practiced and the types of crop, which can be grown successfully. Heavy rainfall helps in leaching down of salts and reduces the salinity level in the soil but seed germination is deteriorated with an increase in the number of rainy days.

5.3.5 Humidity

Humidity, or air moisture content, plays a key role since it influences varieties phases of vegetable production, like seed germination, vegetative growth, flowering, fruit set, quality of vegetables, etc. Besides seed production and seed viability in storage, humidity plays most important role in the occurrence of insect-pests and disease. Certain diseases (*e.g.*, powdery mildew) are associated with dry weather but humid conditions are known to favour diseases, like leaf rust, downy mildew and fungal blights affecting foliage. Humidity and temperature in combinations are well known to influence the growth and production of commercial vegetable crops. High humidity leads to the enhanced disease incidence, such as anthracnose in spinach and *Septoria petroselini* in parsley (Kurt and Tok 2005; Uysal and Kurt 2017).

Excessively high humidity favors the growth of microbes during storage and makes the fruits and vegetables susceptible to disease infection. Besides low temperature, relative humidity is equally important factor in cold storage for maintaining firmness of fresh produce as water loss from vegetables having high water content is rapid at low storage humidity. High humidity prevents wilting of leafy vegetables particularly after harvest. The moisture content positively influences the total plant, stem, and leaf and root weight (Ejieji and Adeniran 2010).

5.3.6 Frost

Most vegetables are injured at or slightly below freezing temperature but tropical and subtropical vegetables may be damaged or permanently killed by temperature below 10 °C but above freezing point. The extent of the damage caused by frost fluctuate species and even with varieties of the same species or to some degree with the stage of plant development.

Frost has a devastating impact on lettuce which is easily identifiable, the extent of which vary according to the duration of exposure to frost and growth stage of lettuce. Frost damage manages itself by the separation of the outer leaf cuticle from the underlying cell tissue, which leads to bronzing of leaves. This occurs due to the damage to the epidermal cells. Severe frost conditions also lead to necrotic spotting as well as interveinal lesions. Sometimes, young leaves tips are dried up and upon the continuation of the leaf growth, curling of the leaves occurs. Shorter exposure of frost causes roughening and thickening of the leaf tissue.

In case of celery, when temperature falls below – 0.5 °C, freezing injury can generally be seen. Water soaked spots appear on thawing and wilted leaves of lettuce. Freezing injury can appear in the field condition in Romain and Crisphead lettuce, resulting in epidermis separation from the leaves. This ultimately leads to attack of bacterial pathogens during storage condition, especially if lettuce is stored at less than 2 °C.

In spinach, freezing injury appears when exposed to −0.3 °C ambient temperature, which leads to water soaking spots accompanied by bacterial soft rot. Palak crop can withstand frost and tolerate warm weather but high temperature leads to early bolting without giving sufficient cuttings. During hot weather leaves pass edible stage quickly.

5.3.7 Hail

Hail storms can beat down a standing crop nearing harvest; do considerable damage to the harvested sheaves left in the field for drying and cause necrotic spots on fruits like tomato, which happened to be hit by hail. Hails pose a serious threat through their mechanical damages to the branches and development of corky tissues in fruits in and around the hail hit spots. Hail damage to leafy tissues can reduce photosynthetic surface and depress yield.

5.3.8 Soil Factors

Vegetables crops generally grow well in fertile soils with regular supply of essential nutrients and moisture. Light textured soils are suitable for lettuce. But, in general loam soils are suitable for almost all vegetable crops. Cool season vegetables are shallow rooted crops, which have short growing season so these crops should be grown in soils warm up quickly but such soils are often low in nutrients and poor in retention of moisture, needing heavy fertilizers application and frequent irrigation. These soils are most suitable for the cultivation of crops in which underground part is of economic importance. However, the crops for which higher yield is more important should be grown in heavy soils, but in such soils, the crops usually take longer time to mature. Heavy soils often considerable plant nutrient reserves and also retain moisture for longer period, thus only small quantity of fertilizers is required, and irrigation is required relatively at long intervals but too heavy soils are not suitable for the cultivation of vegetable crops as they poor aeration and poor nutrient liberation capacity resulting in poor plant growth. Heavy soils produce rough and deformed roots with number of small fibers. Tubers produced in light soils generally have a more desirable shape and brighten skin colour than those are grown in heavy soils.

5.3.8.1 Soil Salinity

The crop growers have to grow crops in many areas around the globe by irrigating with water containing high salt content due to the scarcity of good quality water sources. The physiology, biochemistry as well as yield of leafy vegetable crops get affected by the soil salinity and salinity possess a major threat during production of these vegetables (Munns and Tester 2008). It's been estimated that soil salinity directly negatively affects 20% of irrigated agricultural land (Chinnusamy et al. 2005) and it negatively impacts around 1000 million ha of land, which is 7% of all land area (Szabolcs 1994).

Al-maskri et al. (2010) reported that soil salinity significantly influenced that number of leaves, plant fresh weight, shoot fresh and dry weight, shoot dry matter percentage, root fresh and dry weight, root dry weight percentage, leaf area and leaf area index of lettuce. Unlukara et al. (2008) found that the salinity led to continuous decrease in lettuce yield which went upto 60% yield loss. Omami (2007) reported *A. hypochondriacus* and *A. cruentus* to exhibit enhanced tolerance to salinity, as plants were able to survive in 200 mM NaCl treatment.

5.3.8.2 Heavy Metals

A number of studies reported the high concentration of heavy metals caused in inhibition of vegetative growth and crop productivity. Prolonged exposure of high concentration of heavy metals may lead to decrease in blood pressure and damage to numerous internal organs like liver, kidney, and lungs. It can also negatively influence a number of physical and neurological functions resembling sclerosis. The major heavy metals affecting the commercial cultivation of leafy vegetables are Cadmium, Copper, and lead. At higher concentration doses, cadmium (Cd) and copper (Cu) results in highly toxic impact and the plant growth attributing factors are significantly reduced in case of spinach and amaranthus (Chetan and Ami 2015). Accumulation of lead leads to the reduction in growth and nutrient uptake of the mineral ions such as Sodium, Potassium, Calcium, Magnesium, Iron, Copper and Zinc in spinach (Lamhamdi et al. 2013)).

5.4 Mitigation of Negative Impacts of Climate Change

Negative impact of the global warming can be mitigated by the adoption of sustainable strategies to enhance the production and productivity of the leafy vegetables. There exist numerous ways to continue growing crops even in the changing global climate scenario. Some of these measures are given below:

5.4.1 Strengthening of Crop Management Systems

The production of leafy vegetables cultivated in low land topography exposed to hot and humid climates can be enhanced with the help of numerous management methods. A number of biotic and abiotic stresses combating strategies have been developed by World Vegetable Centre, Taiwan in flood and drought prone as well as saline soil infested areas to produce high qualitative leafy vegetables.

5.4.2 Efficient Irrigation Management

Proper water management significantly positively affect the proper growth and development of leafy vegetable crops due to their high water content of their foliage. The critical stage of irrigation needs to be identified for individual leafy vegetables. The critical period varies according to the prevailing weather condition of the area, crop growth stage, water retention capacity of soil as well as soil texture.

5.4.3 Water Conserving Agronomical Practices

In order to protect the crop especially leafy vegetables susceptible to imbalanced water supply, a number of mitigation strategies are available. Those include the use of raised beds, utilization of rain shelter to protect the crop from heavy rains, and mulching which restricts water loss from soil. These strategies are reported to successfully save the crop from heavy rain, heat stress, excess moisture stress, etc. Growing of leafy vegetables inside protected structures in controlled condition to grow leafy vegetables all around the year.

5.4.4 Promotion of Climate-Resilient Leafy Vegetables

The existence of diverse germplasm is the preliminary requisite for the breeding programme aimed at mitigating the abiotic stresses caused by global warming. Use of abiotic stress resistant cultivars, use of efficient water management strategies and organic method of cultivation need to be more practiced by the crop growers to sustainably grow a crop with high yield and nutritional value.

5.4.5 High Temperatures Tolerance

In order to combine heat tolerance with high productivity, expansion of genome base by crossing the heat tolerant cultivars with high yielding accession followed by selection. A number of cultivars of a number of leafy vegetables have been developed to cultivate in high temperature areas. Various crops are altered and modified for ability to cope with heat tolerance. Minetto, X-01, Green Star, Magenta, Bronze Arrow Lose Leaf, Red Salad Bowl Oakleaf and Oakleaf Looseleaf Lettuce are heat tolerant lettuce cultivars, while Panama, Red Sun, Revolution, Bergamo cultivars are resistant to bolting; hence, recommended for high temperature regions. Similarly, the Japanese hybrids “Akarenso,” “Alrite,” “Alkame,” and “Samba,” spinach cultivars and ‘Conquistador’, ‘Celery Paris’ celery can be selected to grow in high temperature areas. Badi Chaulai, Pusa Lal Chauli *(A.tricolor)* of amaranthus also possess considerable tolerance to heat stress. Pusa Jyoti of Palak has wide adaptability to changing climate and recommended for all the year round cultivation.

5.4.6 Salinity Tolerance

A number of programs are underway to develop salt tolerant high yielding varieties. Although not much success has been achieved through conventional breeding programs, owing to physiologic and genetic complexity of the character (Flowers 2004). For the development of salt tolerant varieties, collection and evaluation of diverse germplasm, suitable method of screening, and successful transfer of salinity tolerance from the donor to the commercial elite genotypes are the main targets. Romanian lettuce cultivars and K_1, Quinoa amaranthus are suitable to cultivate in saline soil condition (Table 5.3).

Table 5.3 Classification of leafy vegetables and salad crops based on Salinity Tolerance

Less tolerant	Moderately tolerant	Tolerant
Celery	Amaranth	Palak
	Spinach	Lettuce

5.5 Conclusion

The key to successful and sustainable vegetable crop production is the process of developing of an understanding of environment and quantifying the agro-climatic requirements of different vegetable crops. Impact of anticipated climate variability on regional scale is the main challenge for a successful vegetable production. Leafy vegetable crops like lettuce, celery, parsley, spinach, etc., can be grown successfully in controlled environment, *viz.*, permanent protected structures or greenhouses where plant growth is not affected by outside environmental conditions. Components of climate like radiation, rainfall, temperature and wind affect microclimate modification within crop fields which are beyond human control. In order to bring forth the full potential of the highly scattered vegetable producing areas to sustainable vegetable producing regions, a great deal of understanding of agro-climatic resources of the region and microclimatic modifications and their interactions with vegetable crops is needed. Thus, by exploring the meteorological conditions through field microclimatic modifications by fulfilling the requirements of crops, the sustainable vegetable production may be achieved.

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