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Climate Change and its Impact on Food Quality

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ABSTRACT

Human activities have changed the composition of the earth's atmosphere resulting in rising global temperatures and sea levels. Continuation of GHG's emission will increase temperature from 1.1-5.4 °C by 2100[20]*. The higher temperatures reduce net carbon gain by increasing plant respiration more than photosynthesis*[3]*. Temperature increase and the effects of greenhouse gases are among the most important issues associated with climate change. The production and quality of fresh fruit and vegetable crops can be directly and indirectly affected by high temperatures and exposure to elevated levels of carbon dioxide and ozone*[35]*. The increase in temperature affects photosynthesis directly, causing alterations in sugars, organic acids, flavonoid contents, firmness and antioxidant activity*[49]*. Carbon dioxide accumulation in the atmosphere has direct effects on postharvest quality causing tuber malformation, occurrence of common scab, and changes in reducing sugars contents on potatoes*[17]*. High concentrations of atmospheric ozone can potentially cause reduction in the photosynthetic process, growth and biomass accumulation. The attack of toxigenic fungi on crops and products has the potential of creating great risk. Mycotoxins are climate dependent, also influenced by non-infectious factors (e.g. bioavailability of (micro) nutrients, insect damage, and other pests attack), that are in turn driven by climatic conditions. Climate represents the key agro-ecosystem driving force of fungal colonization and mycotoxin production*[30]*. Adaptation is needed to reduce adverse impacts of climate change but it also should focus on exploiting possible opportunities via technological, institutional and societal innovations*[20] *(IPCC, 2001). In agriculture adaptation strategies are strongly linked to mitigation strategies, both should be evaluated in coherence and not in isolation.*

Key words: *climate change, food quality, mycotoxins, mitigation.*

INTRODUCTION

The environment has been influenced by human beings for centuries. However, it is only since the beginning of the industrial revolution that the impact of human activities has begun to extend to a global scale. Today, environmental issue has become the biggest concern of mankind as a consequence of scientific evidence about the increasing concentration of greenhouse gases in the atmosphere and the changing climate of the Earth. Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity.

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This usage differs from that in the United Nations Framework Convention on Climate Change[47], where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods. Climate change is considered as posing the greatest threat to agriculture production and food security in the 21st century, particularly in many of the poor, agriculture-based countries of Sub-Saharan Africa (SSA), due to their low capacity to effectively cope with a possible decrease in yields among others.

The Food and Agriculture Organization[14] (FAO) defines food security as a ‘‘situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life’’. This definition comprises four key dimensions of food supplies: availability, stability, accessibility, and utilization. The first dimension relates to the availability of sufficient food, i.e., to the overall ability of the agricultural system to meet food demand. The second dimension, stability, relates to individuals who are at high risk of temporarily or permanently losing their access to the resources needed to consume adequate food, either because these individuals cannot ensure *ex ante* against income shocks or they lack enough ‘‘reserves’’ to smooth consumption *ex post* or both. The third dimension, access, covers access by individuals to adequate resources to acquire appropriate foods for a nutritious diet. Finally, utilization encompasses all food safety and quality aspects of nutrition; its sub dimensions are therefore related to health, including the sanitary conditions across the entire food chain.

Global warming and climate change has emerged as an important global concern cutting across geographical and national boundaries. The on-going over-production of greenhouse gases has meant that more and more heat is being trapped in the earth’s atmosphere, so we are essentially heating up. This is what is known as global warming[46].

Since industrialization, the earth’s temperature has risen by 0.7 degrees- if we do not take action soon, by 2100 temperatures could increase by as much as 5 degrees. This temperature increase will have a dramatic and devastating effect upon the world around us, leading to more extreme weather events and further widespread extinction of many animal and plant species.

Human activities have added greenhouse gases to the atmosphere: CO_2, mainly from deforestation and fossil fuel combustion, methane and nitrous oxides from agriculture and waste, and fluorinated gases from industrial processes. These additional greenhouse gases are responsible for the additional warming of the earth. This is the enhanced greenhouse effect. We can measure greenhouse gases in the atmosphere. Carbon dioxide (CO_2), methane (CH_4), and nitrous oxides (N_2O) concentrations have gone up strongly since the beginning of the industrial revolution. carbon dioxide levels are now about 30% higher than before 1750, N_2O about 50% higher, and CH_4 approximately doubled.

Rising fossil fuel burning and land use changes have emitted, and are continuing to emit, increasing quantities of greenhouse gases into the Earth’s atmosphere. These greenhouse gases include carbon dioxide (CO_2), methane (CH_4) and nitrogen dioxide (N_2O), and a rise in these gases has caused a rise in the amount of heat from the sun withheld in the Earth’s atmosphere, heat that would normally be radiated back into space. This increase in heat has led to the greenhouse effect, resulting in climate change[47].

Factors related to climate change

1. Excessive and unplanned urbanization
2. Unplanned industrial growth
3. Imbalanced use of agricultural inputs and extreme farming
4. Effect of industrial pollution by developed countries
5. Deforestation
6. Burning of fossil fuels

Impacts of climate change

a. Increase in sea water temperature:

Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m and that the ocean has been absorbing more than 80% of the heat added to the climate system. Such warming causes seawater to expand, contributing to sea level rise. At the national level, increase of 0.4° C has been observed in surface air temperatures over the past century. A warming trend has been observed along the west coast, in central India, the interior peninsula, and north-eastern India. However, cooling trends have been observed in north-west India and parts of south India[20].

b. Melting of Mountain glaciers and Snow:

Mountain glaciers and snow cover have declined on average in both hemispheres. Widespread decreases in glaciers and ice caps have contributed to sea level rise (ice caps do not include contributions from the Greenland and Antarctic Ice Sheets). New data since the Third Assessment Report now show that losses from the ice sheets of Greenland and Antarctica have very likely contributed to sea level rise over 1993 to 2003. The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or loss of floating glacier tongues. The remainder of the ice loss from Greenland has occurred because losses due to melting have exceeded accumulation due to snowfall[20].

c. Sea Level Rise:

Global average sea level rose at an average rate of 1.8 [1.3 to 2.3] mm per year over 1961 to 2003. The rate was faster over 1993 to 2003: about 3.1 [2.4 to 3.8] mm per year. There is high confidence that the rate of observed sea level rise increased from the 19th to the 20th century. The total 20th-century rise is estimated to be 0.17 [0.12 to 0.22] m. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic (by up to 3°C). Average arctic temperatures increased at almost twice the global average rate in the past 100 years. Arctic temperatures have high decadal variability, and a warm period was also observed from 1925 to 1945. In India sea level rise has been observed to increase by 0.4–2 mm/year along the Gulf of Kutch and the coast of West Bengal. However, relative decrease along the Karnataka coast has also been observed[20].

d. Shifting trends in precipitation:

Long-term trends from 1900 to 2005 have been observed in precipitation amount over many large regions. Significantly increased precipitation has been observed in eastern parts of North and South America, northern Europe and northern and central Asia. Drying has been observed in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Precipitation is highly variable spatially and temporally, and data are limited in some regions. Long-term trends have not been observed for the other large regions assessed. Changes in precipitation and evaporation over the oceans are suggested by freshening of mid- and high latitude waters together with increased salinity in low latitude waters. Mid-latitude westerly winds have strengthened in both hemispheres since the 1960s[20].

e. Incidence of Floods, Droughts, Earthquakes:

As compared to the past, the frequency and intensity of natural disaster such as flood, drought, earthquake, super cyclone etc. have increased which led to the loss of property and lives. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. Increased drying linked with higher temperatures and decreased precipitation has contributed to changes in drought. Changes in sea surface temperatures, wind patterns and decreased snowpack and snow cover have also been linked to droughts. The frequency of heavy precipitation events has increased over most land areas causing floods, consistent with warming and observed increases of atmospheric water vapour.

f. Monsoon Unpredictability:

Since last several years, the pattern of monsoon onset has become very unpredictable, uncertain and erratic. The observed monsoon rainfall at the all-India level does not show any significant trend, regional monsoon variations have been recorded. A trend of increasing monsoon seasonal rainfall has been found along the west coast, northern Andhra Pradesh and north-western India while a trend of decreasing monsoon seasonal rainfall has been observed over eastern Madhya Pradesh, north-eastern India, and some parts of Gujarat and Kerala.

g. Advance onset of flowering in trees:

Trees are generally a very good bio-indicator of climate change as the flowering in perennial trees takes place as a result of completing the crop-specific required thermal unit/thermal period or degree-days. The very good examples could be the mango trees, which flower according to the thermal regime/period in different parts of the country. The mango tree generally flowers in October-November in south India, in December-January in eastern and central India and middle of February-March in north India. But there has been some evidence of flowering of mango trees in December in north India in the year 2004, which was probably due to prevailing higher regime in December. Thus the flowering behaviour of mango, cherry, apple etc. could be used as a very good bio-indicator for climate change.

h. Changing cropping pattern:

There have been some indications of spatial changes in cropping pattern particularly in hilly mountain areas of Himachal Pradesh. Some apple grown areas have shifted to higher reaches as their traditional belts are exhibiting warmer weather and might become unsuitable for their cultivation. Successful cultivation of wheat in Kashmir during winter period and maize in Bihar are some more examples. Similarly, apple in Kashmir region may experience decline in yield due to increase in winter temperatures in the past years as apple requires narrow range of optimum thermal regime. Pole wards expansion of arable land in the regions where low temperatures are limiting for crop cultivation mainly due to rise in temperature which may be conducive for crop cultivation.

From the post-harvest quality point of view, the major emphasis is on:

1. Temperature
2. Carbon dioxide
3. Ozone

Effect of temperature

Fruit and vegetable growth and development are influenced by different environmental factors[6]. During their development, high temperatures can affect photosynthesis, respiration, aqueous relations and membrane stability as well as levels of plant hormones, primary and secondary metabolites. Seed germination can be reduced or even inhibited by high temperatures, depending on the species and stress level[5]. Most of the temperature effects on plants are mediated by their effects on plant biochemistry. That is, of course, for well water supplied plants, for which the Q_{10} for growth is very high. For plants that are subjected to water deficit, temperature is a physical facilitator for balancing sensible and latent heat exchange at the shoot, which is modulated by relative humidity and by wind. Most of the physiological processes go on normally in temperatures ranging from 0 ^{o}C to 40 ^{o}C. However, cardinal temperatures for the development of fruit and vegetable crops are much narrower and, depending on the species and ecological origin, it can be pushed towards 0 ^{o}C for temperate species from cold regions, such as carrots and lettuce. On the other hand, they can reach 40 ^{o}C in species from tropical regions, such as many cucurbits and cactus species[50]. A general temperature effect in plants involves the ratio between photosynthesis and respiration. For a high yield, not only photosynthesis should be high but also the ratio photosynthesis/ respiration should be much higher than one. At temperatures around 15 ^{o}C, the above mentioned ratio is usually higher than ten, explaining why many plants tend to grow better in temperate regions than in tropical ones[50]. Higher than normal temperatures affect the photosynthetic process through the modulation of enzyme activity as well as the electron transport chain[35]. Additionally, in an indirect manner, higher temperatures can affect the photosynthetic process increasing leaf temperatures and, thus, defining the magnitude of the leaf-to-air vapor pressure difference (D), a key factor influencing stomatal conductance[27]. Photosynthetic activity is proportional to temperature variations. High temperatures can increase the rate of biochemical reactions catalyzed by different enzymes. However, above a certain temperature threshold, many enzymes lose their function, potentially changing plant tissue tolerance to heat stress.

Rapid cooling

Fruit and vegetable crops are generally cooled after harvest and before packing operations. Cooling techniques have been used since the 1920s to remove field heat from fresh produce, based on the principle that shelf-life is extended 2- to 3-fold for each 10 °C decrease in pulp temperature. Rapid cooling optimizes this process by cooling the product to the lowest safe storage temperature within hours of harvest. By reducing the respiration rate and enzyme activity, produce quality is extended as evidenced by slower ripening/senescence, maintenance of firmness, inhibition of pathogenic microbial growth and minimal water loss[42]. Rapid cooling methods such as forced-air cooling, hydrocooling and vacuum cooling demand considerable amounts of energy[45]. Therefore, it is anticipated that under warmer climatic conditions, fruit and vegetable crops will be harvested with higher pulp temperatures, which will demand more energy for proper cooling and raise product prices.

Fruit ripening

High temperatures on fruit surface caused by prolonged exposure to sunlight hasten ripening and other associated events. One of the classical examples is that of grapes, where berries exposed to direct sunlight ripened faster than those ripened in shaded areas within the canopy. Ripening of ‘Hass’ avocados was also affected by exposure to high temperatures during growth and development. Fuerte’ and ‘Hass’ fruits exposed to direct sunlight were firmer than fruits of the shaded areas. Cell wall enzyme activity (cellulose and polygalacturonase) was negatively correlated with fruit firmness, indicating that sun exposure, i.e., higher temperatures during growth and development, can delay ripening. However this delay did not occur via a direct effect on the enzymes associated with cell wall degradation[8]. Tomato ripening occurred normally in terms of color development, ethylene evolution, and respiratory climacteric after three days at temperatures above 36°C. However, ripening was slower than freshly harvested fruit[29].

Quality parameters

Extensive work has been carried out for more than three decades focusing quality properties of fruit and vegetable crops exposed to high temperatures during growth and development. Flavour is affected by high temperatures. Apple fruits exposed to direct sunlight had a higher sugar content compared to those fruits grown on shaded sides[7]. Grapes also had higher sugar content and lower levels of tartaric acid when grown under high temperatures. Coombe[9] observed that a 10 °C increase in growth temperature caused a 50% reduction in tartaric acid content. Lakso and Kliewer[24] verified that malic acid synthesis was more sensitive to high temperature exposure during growth than was the synthesis of tartaric acid. Fruit firmness is also affected by high temperature conditions during growth. ‘Fuerte’ avocados exposed to direct sunlight (35 °C) were 2.5 times firmer than those positioned on the shaded side (20 °C) of the tree. Changes in cell wall composition, cell number, and cell turgor properties were postulated as being associated with the observed phenomenon[53]. Dry matter content is used as a harvest indicator for avocados due to its direct correlation with oil content, a key quality component. They also noted that higher temperature influenced oil composition, where the concentration of certain specific fatty acids increased (e.g., palmitic acid by 30%) whereas others did not (e.g. oleic acid). Avocados with higher dry matter content take longer to ripen which could pose a serious problem for growers planning to market their fruits immediately after harvest[53].

Antioxidant activity

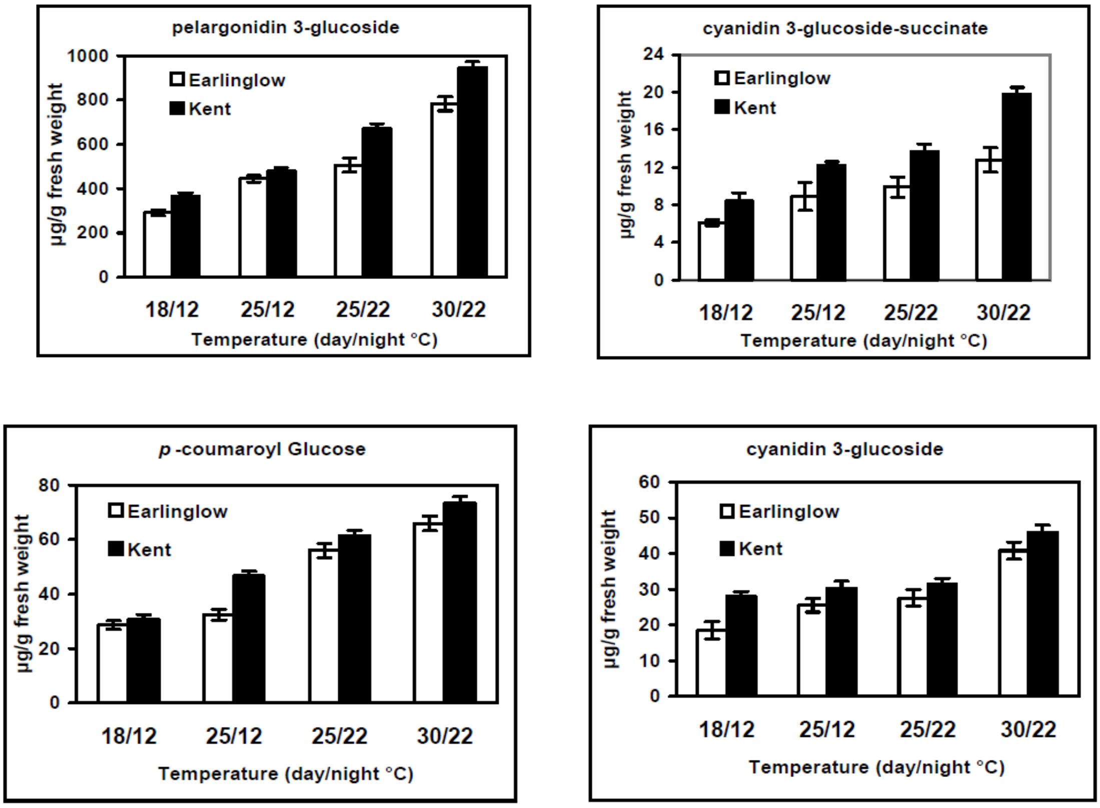
Antioxidants in fruit and vegetable crops can also be altered by exposure to high temperatures during the growing season. Wang and Zheng[49] observed that 'Kent' strawberries grown in warmer nights (18–22 °C) and warmer days (25 °C) had a higher antioxidant activity than berries grown under cooler (12 °C) days The investigators also observed that high temperature conditions significantly increased the levels of flavonoids and, consequently, antioxidant capacity. Galletta and Bringhurst[15] verified that higher day and night temperatures had a direct influence in strawberry fruit color. Berries grown under those conditions were redder and darker.

Physiological disorders

Exposure of fruit and vegetable crops to high temperatures can result in physiological disorders and other associated internal and external symptoms

Crop	Symptoms
Beans	Brown and reddish spots on pods; spots coalesce and form water-soaked area
Cabbage	Outer leaves showing a bleached, papery appearance; become more susceptible to decay
Apple	Skin discoloration, pigment breakdown and water-soaked areas
Tomato	Sunburn: disruption of lycopene synthesis
Potato	Black heart: symptoms usually occur in the centre of the tuber as dark-gray to black discoloration
Avacado	Skin and flesh browning; increased decay susceptibility
Pineapple	Flesh with scattered water-soaked areas
Lime	Juice vesicle rupture; formation of brown spots on fruit surface

Effect of plant growth temperature on flavonoids content in strawberry fruits



Effects of carbon dioxide

The Earth’s atmosphere consists basically of nitrogen (78.1%) and oxygen (20.9%), with argon (0.93%) and carbon dioxide (0.031%) comprising next most abundant gases[26]. Nitrogen and oxygen are not considered to play a significant role in global warming because both gases are virtually transparent to terrestrial radiation. The greenhouse effect is primarily a combination of the effects of water vapour, carbon dioxide and minute amounts of other gases (methane, nitrous oxide, and ozone) that absorb the radiation leaving the Earth´ s surface[20]. The warming effect is explained by the fact that carbon dioxide and other gases absorb the Earth’s infrared radiation, trapping heat. Since a significant part of all the energy emanated from Earth occurs in the form of infrared radiation, increased carbon dioxide concentrations mean that more energy will be retained in the atmosphere, contributing to global warming[27]. Carbon dioxide- concentrations in the atmosphere have increased approximately 35% from pre-industrial times to 2005[20].

Quality parameters

Högy and Fangmeier[17] studied the effects of high carbon dioxide concentrations on the physical and chemical quality of potato tubers. They observed that increases in atmospheric carbon dioxide (50% higher) increased tuber malformation in approximately 63%, resulting in poor processing quality, and a trend towards lower tuber greening (around 12%). Higher carbon dioxide levels (550 µmol CO_2/mol) increased the occurrence of common scab by 134% but no significant changes in dry matter content, specific gravity and underwater weight were observed. Higher (550 µmol CO_2/mol) concentrations of carbon dioxide increased glucose (22%), fructose (21%) and reducing sugars (23%) concentrations, reducing tubers quality due to increased browning and acryl amide formation in French fries. They also observed that proteins, potassium and calcium levels were reduced in tubers exposed to high carbon dioxide concentrations, indicating loss of nutritional and sensory quality. Bindi *et al*[6]., studied the effects of high atmospheric CO_2 during growth on the quality of wines. These authors observed that elevated atmospheric CO_2 levels had a significant effect on fruit dry weight, with increases ranging from 40 to 45% in the 550 µmol CO_2/mol treatment and from 45% to 50% in the 700 µmol CO_2/mol treatment. Tartaric acid and total sugars contents increased around 8% and 14%, respectively, by rising CO_2 levels up to a maximum increase in the middle of the ripening season. However, as the grapes reached the maturity stage, the CO_2 effect on both quality parameters almost completely disappeared.

Growth and physiological alterations

Many papers published during the last decade have clearly associated global warming with the increase in carbon dioxide concentration in the atmosphere. Changes in carbon dioxide-concentration in the atmosphere can alter plant tissues in terms of growth and physiological behaviour. Many of these effects have been studied in detail for some vegetable crops[4,11,18]. These studies concluded, in summary, that increased atmospheric carbon dioxide alters net photosynthesis, biomass production, sugars and organic acids contents, stomatal conductance, firmness, seed yield, light, water, and nutrient use efficiency and plant water potential.

Physiological and quality parameters of fruit and vegetable crops affected by exposure to increased CO_2 levels.

Physiological or quality parameter	**Effect of high carbon dioxide**	**Product**
Photosynthesis	⇧	Potato ; spinach
Respiration	⇩	Asparagus ; broccoli; tomatoes
Ripening	⇩	Tomato
Stomatal conductance	⇩	Spinach
Firmness	⇧	Strawberry
Dry matter	⇧	Potato
Starch	⇧	Potato

Impact of enhanced atmospheric CO_2 on the proximate composition of tomato fruit

Parameter	**Carbon dioxide concentration (µmol/mol)**	
	400	1,000
Ascorbic acid (mg /100g)	53.78 ± 3.841	71.44± 3.065
Protein (%)	15.36± 0.750	12.55± 1.200
Total sugars (%)	33.31± 1.101	38.68± 1.424
Reducing sugars (%)	30.56± 0.435	35.34± 1.312
Non-reducing sugars(%)	2.62± 0.929	3.18± 0.278
Fibre (%)	9.58± 0.276	10.08± 0.114
Ash (%)	10.99±0.210	9.74± 0.355

Effect of elevated carbon dioxide treatments on aroma volatile composition of strawberry fruit

Aroma compound(ng/g dry weight)	**Carbon dioxide treatment (µmol/ mol)**		
	Ambient (350)	Ambient +300	Ambient +600
Ethyl hexanoate	651.3	814.9	962.2
Ethyl butanoate	530.2	637.8	714.3
Methyl hexanoate	294.2	364.44	495.1
Methyl butanoate	219.4	298.5	404.2
Hexyl acetate	168.5	262.6	334.5
Hexyl hexonate	125.8	267.2	311.8
Methyl octanoate	49.2	63.12	92.99

Effects of ozone

Ozone in the troposphere is the result of a series of photochemical reactions involving carbon monoxide (CO), methane (CH_4) and other hydrocarbons in the presence of nitrogen species ($NO + NO_2$)[37] (Schlesinger, 1991). It forms during periods of high temperature and solar irradiation, normally during summer seasons[31]. Another potential source for increased levels of ozone in a certain region is via the movement by local winds or downdrafts from the stratosphere.

Visible injury and physiological effects

The effects of ozone on vegetation have been studied both under laboratory and field experiments. Stomatal conductance and ambient concentrations are the most important factors associated with ozone uptake by plants. Ozone enters plant tissues through the stomates, causing direct cellular damage, especially in the palisade cells[31]. The damage is probably due to changes in membrane permeability and may or may not result in visible injury, reduced growth and, ultimately, reduced yield[23] Since leafy vegetable crops are often grown in the vicinity of large metropolitan areas, it can be expected that increasing concentrations of ozone will result in increased yellowing of leaves. Leaf tissue stressed in this manner could affect the photosynthetic rate, production of biomass and, ultimately, postharvest quality in terms of overall appearance, color and flavor compounds. Exposure of other crops to elevated concentrations of atmospheric ozone can induce external and internal disorders, which can occur simultaneously or independently. These physiological disorders can lower the postharvest quality of fruit and vegetable crops destined for both fresh market and processing by causing such symptoms as yellowing (chlorosis) in leafy vegetables, alterations in starch and sugars contents of fruits and in underground organs. Decreased biomass production directly affects the size, appearance and other important visual quality parameters. Furthermore, impaired stomatal conductance due to ozone exposure can reduce root growth, affecting crops such as carrots, sweet potatoes and beet roots[13].

Quality parameters

Skog and Chu[40] carried out a set of experiments to determine the effectiveness of ozone in preventing ethylene-mediated deterioration and postharvest decay in both ethylene-sensitive and ethylene-producing commodities, when stored at optimal and sub-optimal temperatures Strawberries cv. Camarosa stored for three days under refrigerated storage (2 ^{o}C) in a ozone-enriched atmosphere (0.35 µL/L) showed a 3-fold increase in vitamin C content when compared to berries stored at the same temperature under normal atmosphere as well as a 40% reduction in emissions of volatile esters in ozonized fruits[33]. Quality attributes and sensory characteristics were evaluated on tomato fruits cv. Carousel after ozone exposure (concentration ranging from 0.005 to 1.0 µmol/mol) at 13 ^{o}C and 95% RH. Soluble sugars (glucose, fructose), fruit firmness, weight loss, antioxidant status, CO_2/H_2O exchange, ethylene production, citric acid, vitamin C (pulp and seed) and total phenolic content were not significantly affected by ozone treatment when compared to fruits kept under ozone-free air. A transient increase in b-carotene, lutein and lycopene content was observed in ozone-treated fruit, though the effect was not consistent. Ozone-treated fruit showed the highest values of weight loss and maximum electrolyte leakage.

Physiological and quality parameters of fruit and vegetable crops affected by exposure to increased O_3 levels

Physiological or quality parameter	O_3 effect	Product	Reference
Photosynthesis	⇩	Strawberry ;conifers	Amthor and Cumming[1]
Visible injury	⇧	Black cherry	Chappelka *et al*[2].,
Reducing sugars	⇩	Potato	Vorne *et al*[48].,
Ascorbic acid	⇩	Potato	Vorne *et al*[48].,
Firmness	⇧	Cucumber	Skog and Chu[40]
Electrolyte leakage	⇧	Persimmon	Salvador *et al*[36].,

Impact of climate change on food quality

Carbohydrates

The effects of temperature and elevated carbon dioxide on carbohydrate composition of food crops are mixed and probably reflect differences in experimental conditions (e.g., carbon dioxide enrichment technologies and rooting volume) in addition to being species- or even cultivar-dependent. However, the preponderance of evidence suggests that increases in temperature should have a larger effect than elevated carbon dioxide-concentration on carbohydrate composition, as can be seen below. In soybean seeds, carbohydrate composition significantly changed with increasing temperature from 18/13 °C to 33/28 °C (day/ night). Whereas sucrose concentration increased, stachyose decreased slightly; other sugars, such as glucose, raffinose and fructose did not change significantly with rising temperature[52]. In wheat, small increases in temperature (2–4 °C) may also have more than twice the effect of carbon dioxide-concentration on grain quality, as shown by Williams *et al*[51]., who noted that starch content, starch grain size and number, and gelatinization were all altered in complex ways with temperature, but with little effect of increased carbon dioxide concentration. Thomas *et al*[44]., studying the combined effects of temperature (28/18 °C and 34/ 24 °C; day/night) and carbon dioxide -concentration (350 and 700 ppm) on the composition of red kidney beans seeds, also found that seed composition was unaffected by elevated carbon dioxide –concentration- but seeds produced at 34/24 °C showed decreased glucose concentration (44%) and significantly increased concentrations of sucrose (33%) and raffinose (116%) compared to the 28/18 °C treatment. These changes may have important consequences for food quality; for example, Sebastian *et al*[38]., reported that increases in raffinose amounts create digestive problems in both non-ruminant animals and humans, where the intestinal mucosa does not contain the galactosidase enzyme necessary to digest raffinose High temperature (37/17 °C) from flowering to grain maturity caused a significant reduction in the starch accumulation period in developing wheat grains compared with plants grown under control (24/17 °C; day/night) conditions. When extremely high temperatures (37/28 °C; day/night) were applied, starch incorporation was completed 21 days earlier than in the control, with an increased proportion of A-type starch granules (10–50 µm diameter) and a decreased proportion of B granules (5–10 µm diameter). This result is consistent with shorter starch accumulation, as observed at high temperatures in wheat and barley[3]. Yang *et al*[54]., also under FACE conditions, found lower amylose content (3.6%), decreased hardness of the rice grains, and improved palatability. However, elevated carbon dioxide concentration caused serious deterioration of processing suitability (decreased milled rice percentage and head rice percentage – 2.0% and 23.5%, respectively) and appearance quality (increased chalky grain percentage and chalkiness degree _16.9% and 28.3%, respectively).

Minerals

In rice, Seneweera and Conroy[39] found lower concentrations of four out of five measured elements: N (14%), P (5%), Fe (17%) and Zn (28%), but calcium increased (32%) under elevated CO_2. In wheat, Loladze analyzed five published studies and noted slight decreases (ranging from ca. 3% to 10%, though significant) in P, Mg and Zn, and decreases superior to 10% in the concentrations of N, Ca, S, Fe, and Zn, whereas K concentration increased slightly. Högy and Fangmeier[17] (2008) also noted high- CO_2-induced decreases in the concentrations of all micronutrients by 3.7–18.3% over a range of carbon dioxide-enrichment technologies, with the exception of Fe, which increased by 1.2% (but not significantly) in closed field chambers. The decreases in essential elements in grains of major crops such as wheat and rice are to be expected, which, ultimately, will aggravate the already acute malnutrition in the world, putting millions at risk of the ‘‘hidden hunger” of micronutrient malnutrition[41].

Lipids

In soybean, oil content was positively correlated with increasing temperature from 25 °C to 36°C[52]. Thomas *et al*[43]., studied the combined effects of temperature and carbon dioxide concentration on the composition of soybean seeds and found that oil yield was highest at 32/22 °C (day/night) and decreased with further increase in temperature. Oleic acid concentration increased with increasing temperature; whereas linolenic acid decreased Changes in fatty acid composition, such as the concentration of oleic acid, are associated with nutritional aspects as well as storage longevity (oleic acid is less susceptible to oxidation than linolenic acid). In wheat, quantitative changes in oil composition observed in both non-starch and starch lipid fractions were also much more dependent on elevated temperature (+4 °C above ambient temperature) than on elevated carbon dioxide concentration (twice above ambient carbon dioxide concentration).

Proteins and their fractions

For wheat, barley and rice, the reduction in grain protein ranged from 10% to 15% of the value of ambient carbon dioxide-concentration (315–400 ppm). For potato, the high- carbon dioxide concentration -induced reduction in tuber protein concentration was 14% and, for soybean- there was a much smaller, although statistically significant, decrease in protein concentration of 1.4%. In wheat, the proportions and properties of the two main classes of gluten storage proteins (glutenin and gliadin), each of which comprises between 35% and 45% of the total grain proteins, are primarily responsible for dough and bread-making quality. In OTC experiments with potted plants, concentrations of these proteins have been shown to decrease at elevated carbon dioxide concentration, but this response seems to be cultivar-dependent[17]. Högy and Fangmeier[17] concluded that, in addition to the reduced protein concentration and possible changes in protein composition in grains, the concentrations of amino acids were significantly reduced by between 7.7% and 23.9% due to carbon dioxide- enrichment.

Other food components

Elevated temperatures (especially if coupled with drought stress) are often associated with production of smaller, more fibrous leaves, which usually exhibit changes in nutritional quality, for example, decreasing N and increasing tannins and phenols. At elevated carbon dioxide concentration, tannin and terpene contents also usually increase, especially under ample N supply[18]. Elevated carbon dioxide concentration has also been demonstrated to increase the production of heart-helping digoxin in the wooly foxglove (*Digitalis lanata*) and a suite of cancer fighting substances found in the common spider lily (*Hymenocallis littoralis*)[18].

Quality of animal forage

The combination of increased carbon dioxide concentration, in conjunction with changes in rainfall and temperature, are likely to have significant impacts on grasslands and rangelands, e.g., increased biomass production in humid temperate grasslands. However, these positive effects of elevated carbon dioxide concentration on forage quantity are likely to be lesser than the negative effects on forage quality. The negative effects of elevated carbon dioxide concentration on forage N and crude protein concentrations are usually greater than for fiber (e.g., celluloses, lignin) fractions, which can result in lower digestibility under high carbon dioxide concentration[18]. The reduction in N and crude protein content in forage crops may reflect an interaction between elevated carbon dioxide concentration and low-N fertilizer inputs and may have implications for protein quality (i.e., digestibility and amino acid composition) for non-ruminant animals[34].

Impact on meat quality

Climate change could affect meat quality in one of two ways. There could be an effect through changing farming or abattoir practice to adapt to the climate change, and there could be a direct effect of the changing weather conditions on the animals. Examples of indirect effects include:

1. Changing the genotype of animals by introducing more heat tolerant breeds;
2. Holding animals outdoors instead of housing them during winter;
3. Feeding low protein-high fat finisher rations to combat heat induced growth suppression;
4. Pre-conditioning animals to hot conditions so they will be better adapted to survive heat stress during transport to a processing plant.

Climate change could impact on meat safety as well as organoleptic quality (Table-4). Global warming could affect microbial burdens on carcasses and meat, especially if the animals carry more enteric pathogens in their gut or on their body surface. One way of determining whether this is likely to happen is to examine whether there is presently a seasonal bias in carcass contamination[12]. First, extreme heat provokes an adrenergic stress response. Adrenaline stimulates peripheral vasodilatation and muscle glycogenolysis, and if exposure is protracted before slaughter it could lead to high pH and darker meat. However, in the case of sheep and broiler chickens, the acute heat stress that provokes sufficient adrenaline response to affect meat quality is very severe and is near the lethal limit[28]. Second, if an animal is exercised and develops hyperthermia before it is slaughtered, the combination of high temperature and anaerobic metabolism leads to an early, stronger rigor. There is a risk that the meat could be tougher through a heat-shortening effect, and this can occur in heat stressed animals that do not undergo forced exercise. In the case of pigs and turkeys the meat may also be paler in colour with more drip forming when presented as cuts[16]. Third, protracted high temperatures will lead to dehydration in water deprived animals and this can affect meat quality by making it darker in colour through shrinkage of the myofibres, and because of its dryness it has less weight loss during cooking[21].

Table 4: Potential consequences of climate change on meat quality

Primary change	Potential effects
Periodic warmer climate (heat stress)	❑ Provokes an adrenergic stress response (darker meat) ❑ Hyperthermia (high temperature and anaerobic metabolism) leads to an early, stronger rigor, becomes pale . ❑ Dehydration can affect meat quality by making it darker in colour through shrinkage of the myofibres. (drier and more sticky) ❑ Meat safety (*salmonella sp. or campylobacter sp.*) reduced ❑ *Escherichia coli* contamination of carcasses, ❑ Changes in the frequency of mortality during transport and lairage,

Climate change and mycotoxins

Some toxic low molecular weight compounds produced by filamentous fungi are referred to as mycotoxins and they might contaminate food and feeds. Severe health problems and death have occurred from mycotoxin consumption. Whereas there are many factors involved in mycotoxin contamination. Production of these compounds, for example, on crops, is highly susceptible to environmental factors (e.g. temperature) and available moisture, pre- and/or post-harvest. When climate change occurs, mycotoxin production will be affected[32]. The attack of toxigenic fungi on crops and products has the potential of creating great risk. Mycotoxin production is climate dependent, plant- and storage-associated problem, also influenced by non-infectious factors (e.g. bioavailability of (micro) nutrients, insect damage, and other pests attack), that are in turn driven by climatic conditions. Climate represents the key agro-ecosystem driving force of fungal colonization and mycotoxin production[30].

Mycotoxins	**Commodity**
Aflatoxins	**Peanuts, corn, wheat, cottonseed, nuts, milk**
Citrinin	**Cereal grain (wheat, barley, corn, rice)**
Cyclopiazonic acid	**Corn, peanut ,cheese**
Ochratoxin A	**Cereal grain (wheat, barley, oats, corn), dry beans, cheese, coffee, raisins, grapes, dried fruits, wine,**
Patulin	**rotten apples, apple juice, wheat straw residue**
Penicillic acid	**Stored corn, cereal grains, dried beans, mouldy tobacco**

Temperature and rainfall (together with sea levels) are the climatic factors that are most likely to be affected widely by future global change, and alterations in these are expected to have a wide range of impacts on plants and on their pathogens[19], including mycotoxins concentrations in plants[32]. Global warming will not only act on pathosystems already present in certain regions, but will favour the emergence of new diseases, because (i) distributional range, temporal activity and community structure of pathogens will be modified (ii) phenology and conditions of the hosts will be altered[22]. Rain, at or near harvest, forcasts unacceptable concentrations of aflatoxin in many crops in warm regions. Anecdotal evidence from oil mills and elevators in areas prone to aflatoxin indicates high daily temperature minima leading to ‘‘poisoned crops”[10]. However, a great deal of variation has been observed. Semi-arid to arid and drought conditions in tropical countries are associated with contamination: changes in climate may lead to acute aflatoxicosis and deaths due to the consumption of poor crops which occur even in modern times[25].

Adaptation to climate change

Adaptation refers to the modification of biological and non-biological mechanism or measures, which help the organism to cope with the new sets of environmental stresses following upon their exposure for their survival, growth and development. But there is a limit of adaptation to what extent and magnitude the organism is flexible to modify them. Almost all organisms have the ability to modify their biological systems in order to cope with the environmental stresses to varying extent for their survival and production. Apart from natural adaptability of organism including crop plants, some of the man-made coping strategies could also be practised /implemented to minimize the climatic risks. For developing countries like India, adaptation requires assisting the vulnerable population during adverse climate events and empowering them to build their lives and to cope with climate risks in the long term. In this context, several of India's social-sector schemes emphasize livelihood security and welfare of the weaker sections.

Some of the natural and man-made adaptation mechanisms are discussed as below:

Natural adaptation: crops and animals show varying ability to adapt them to warming through different adaptive mechanism such as shifting their optimum thermal range, escaping, avoidance, thermal cooling, stomatal closure, cutinisation, waxination, development of heat shock protein, osmoregulation etc.,

Genetic adaptation: breeding crop varieties for heat tolerance through conventional and modern breeding techniques. Screening heat tolerant crop genotypes followed by exploitation of desirable genes mainly from the germplasm adapted to such warmer condition.

Non-genetic adaptation: agro-physiological manipulation such as dates of sowing, frequent irrigation, higher dose of chemical fertilizers, crop diversification, green manuring etc. to reduce vulnerability to climate change. Identification of crop genotypes for faster grain growth rate with delayed leaf senescence under higher thermal regime.

Biotechnological approaches: Selective gene transfer from donor without major changes in genetic makeup.

Crop insurance: Reducing climatic risk of crop productivity through crop insurance.

Better support price and credits: Better support price of agricultural produce is and bank credits are essential for crop sustainability and to meet the additional adaptation cost of climate change.

Post-harvest management strategies

1. Growing and/or storing crops and varieties which are less susceptible to post-harvest pest attack
2. Prompt harvesting
3. Careful store cleaning and hygiene
4. Protection and monitoring of grain to be stored for more than three months
5. Adequate cooling
6. Understanding and application of basic food safety principles
7. Increasing farmer access to market information and transport options
8. Use of early warning seasonal forecasts to project how the climatic conditions might impact on food
9. Storage or marketing strategies
10. Use of more water, energy and resource efficient processing, packaging and transport operations
11. Ensuring plant breeders evaluate post-harvest as well as pre-harvest crop characteristics

Mitigation strategies

1. Increase vegetation cover or green belt by plantation of the potential sequestration species.
2. Nutrient and manure management in the livestock to cut down methane emissions.
3. Conservation of water, rain water harvesting and reuse of waste water.
4. Adoption of the organic agriculture.
5. Effective disaster management.
6. Plantation around road sides, industrial complexes and in residential areas.
7. Containment of deforestation to increase Carbon- sinks

Need of hour

Scientific research that can improve our understanding of the interactions of rising carbon dioxide with other environmental variables, such as temp., ozone, water supply as well as biotic factors such as pests and disease. It should be directed towards selecting promising genotypes for a changing global climate.

Conclusion

Temperature, CO_2, ozone and other GHG's directly or indirectly affect the production and quality of fruits and vegetables grown in different climates around the world. Temperature variation can directly affect crop photosynthesis, and a rise in global temperature can be expected to have significant impact on post-harvest quality by altering important quality parameters such as synthesis of sugars, organic acids, antioxidants and firmness. Prolonged exposure to carbon dioxide increases sugars content in potato and diminishes protein and mineral content, leading to loss of nutritional and sensory quality. Elevated levels of ozone induce visible injury and changes in dry matter, reducing sugars, citric and malic acid, among other important quality parameters. Reliable methods to avoid future exposure of vast human populations to unacceptable mycotoxin levels are needed. Mycotoxin management technologies, detoxification, and shifting of cropping patterns are all potential solutions.

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