A REVIEW

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Impact of climate change on quality and nutritional value of food

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Climate change is recognized as a significant manmade global environmental challenge. It is also treated as a threat. The changing climatic environment is a major cause for concern and is now the greatest environmental challenge facing the world today. The increasing unnatural accumulation of green house gases in the atmosphere is now causing global climate change. Carbon emissions related to human activities have been significantly contributing to the elevation of atmospheric (CO_2) and temperature. However, the beneficial direct impact of elevated (CO_2) on food production and quality can be offset by other effects of climate change, such as elevated temperatures and altered patterns of precipitation. Changes in food quality and nutritional value in a warmer, high-CO_2 world are to be expected, e.g., decreased protein and mineral nutrient concentrations, as well as altered lipid composition. We point out that studies related to changes in food quality and nutritional value as a consequence of global climatic changes should be priority areas for further studies, particularly because they will be increasingly associated with food security.

Key words : Climate change, Food production, Food quality, Food security

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INTRODUCTION

The newly emerging threat of climatic change influenced the food production and food nutrients. Consuming more food could also provide the necessary protein or nutrients. But this option is impractical, particularly if food distribution, supply and cost are already threatened by climate change. With climate changes in future, natural calamities (drought, flood, forest fire, fluctuation in rainfall pattern, etc.) will be a serious threat to human survival by way of availability of foods. This will lead to poor production as well as poor nutritional composition of food which cause: Hunger and hidden hunger. This paper focus about what is climate change and how it affects the quality and nutritional value of food.

Climate change :

All GHGs contribute to global warming. To provide a better picture of the direct effect of all GHG combined, scientists formulate a GHG-concentration target in terms of CO_2-equivalent (CO_2-eq) concentration weighting the concentrations of the different gases by their "global warming potential". A level of 350 ppm CO_2-eq concentration in the atmosphere would increase the global surface temperature by an additional 1ºC above pre-industrial times (Fig. 1). The Intergovernmental Panel on Climate Change (IPCC) concluded that such level of GHG concentrations would be the safe upper limit. A further increase in the mean global surface temperature would exacerbate the risks of climate change. The Advisory Group on Greenhouse Gases (AGGG) determined that an increase of 2ºC above preindustrial times would be dangerous. A 2ºC increase would be 'an upper limit beyond which the risks of grave damage to ecosystems are expected to increase rapidly' (AGGG, 1986). The level of concentrations of all GHGs combined reached 375 ppm CO_2 eq (IPCC, 2007c) in 2004. Current levels are estimated at 387 ppm CO_2-eq. Current increase rates of CO_2 are about 0.5 per cent per year (WMO, 2009). By 2020, CO_2 concentrations would reach, at least, a level of 410 ppm. These levels of CO_2 would correspond to GHGs concentrations above 490 ppm CO_2-eq. The IPCC projected that a level of GHG concentrations of 490 CO_2 eq would result in, at least, a 2.4ºC temperature increase (IPCC, 2007c) above pre-industrial times.

General trend of climate change :

The changes in climate parameters are being felt globally

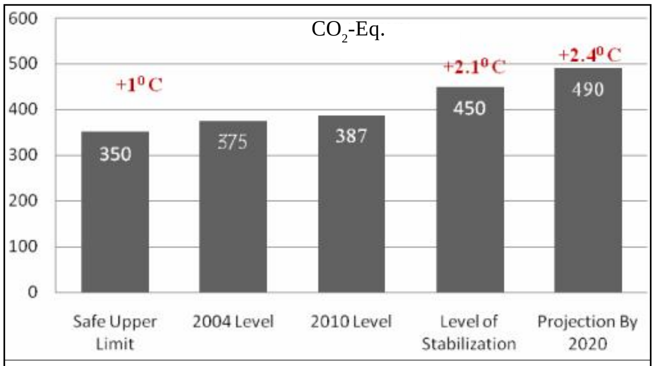

Fig. 1 : CO_2-equivalent

in the form of changes in temperature and rainfall pattern. The global atmospheric concentration of carbon dioxide, a greenhouse gas (GHG) largely responsible for global warming, has increased from a pre-industrial value of about 280 ppm to 387 ppm in 2010. Similarly, the global atmospheric concentration of methane and nitrous oxides, other important GHGs, has also increased considerably resulting in the warming of the climate system by 0.74°C between 1906 and 2005 (IPCC, 2007 b). Of the last 12 years (1995–2006), 11 years have been recorded as the warmest in the instrumental record of global surface temperature (since 1850). The global average sea level rose at an average rate of 1.8 mm per year over 1961 to 2003. This rate was faster over 1993 to 2003, about 3.1 mm per year (IPCC, 2007 a). There is also a global trend of an increased frequency of droughts as well as heavy precipitation events over many regions. Cold days, cold nights and frost events have become less frequent, while hot days, hot nights and heat waves have become more frequent. It is also likely that future tropical cyclones will become more intense with larger peak wind speeds and heavier precipitation. The IPCC (2007) projected that temperature increase by the end of this century is expected to be in the range 1.8 to 4.0°C. For the Indian region (South Asia), the IPCC projected 0.5 to 1.2°C rise in temperature by 2020, 0.88 to 3.16°C by 2050 and 1.56 to 5.44°C by 2080, depending on the future development scenario (IPCC 2007 b).

Carbohydrates :

Plants convert carbon dioxide to high energy compounds such are starch using sunlight and water. The enzyme that catalyses this process (Rubisco, Ribulose bisphosphate carboxylase/oxygenase) is the most abundant protein on earth, making up to 50 per cent of leaf protein and about 25 per cent of leaf nitrogen. Rubisco also catalyses another reaction that uses oxygen in a wasteful process called photorespiration, which can consume up to 20 per cent of the energy trapped from the sun. As the concentration of CO_2 in the atmosphere increases, the CO_2-fixing function of Rubisco is favoured over the oxygenase function. This is called C_3 photosynthesis because the first product contains three carbons. Some plants overcome the problem of photorespiration by increasing the concentration of CO_2 in the vicinity of Rubisco, inserting a preliminary step in the carbon fixation process. These plants are called C_4 plants because the first product is a four carbon compound, usually malate, although they still have the other C_3 process as well. Fast growing summer grains such as maize and sorghum are C_4 plants. Sunflowers, mung beans and soybeans are C_3 plants. With rising CO_2, C_3 plants become more efficient while the gain in efficiency for C_4 plants is much smaller.

In soybean seeds, carbohydrate composition significantly changed with increasing temperature from 18/13^{0}C to 33/28 ^{0}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. Thomas *et al.* (2009), studying the combined effects of temperature (28/18 ^{0}C and 34/ 24 ^{0}C; day/night) and CO_2 (350 and 700 parts per million (ppm)) on the composition of red kidney beans seeds, also found that seed composition was unaffected by elevated CO_2, but seeds produced at 34/24 ^{0}C showed decreased glucose concentration (44%) and significantly increased concentrations of sucrose (33%) and raffinose (116%) compared to the 28/18 ^{0}C treatment. These changes may have important consequences for food quality; for example, Sebastian *et al.* (2000) 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^{0}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 ^{0}C; day/night) conditions. When extremely high temperatures (37/28^{0}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 lm diameter) and a decreased proportion of B granules (5–10 lm diameter). This result is consistent with shorter starch accumulation, as observed at high temperatures in wheat and barley (Barnabás *et al.* (2008) and references therein). In barley, loss of fermentable sugars in the form of degraded starch, associated with high temperatures during grain-filling, might represent a considerable financial penalty in terms of commercial malting production. Nonetheless, Porteaus *et al.* (2009) recently examined two wheat cultivars grown under two N applications in a FACE system (elevated CO_2=550 ppm) and found increased starch concentration at high CO_2 regardless of the N nutrition and cultivars. In any case, Porteaus *et al.* (2009) noted only minor alterations in carbohydrate composition in wheat grains in response to CO_2 enrichment e.g., slight increases in hemicellulose concentration but unaltered concentrations of water soluble carbohydrates, cellulose and lignin. In rice, the content of amylose as well as the rheological properties and temperature of gelatinization largely determine the grain quality. The available information on amylose content at elevated CO_2 is contradictory, however. Amylose content and palatability were both unresponsive to elevated CO_2, as shown by Terao *et al.* (2005) in FACE studies. In contrast, Yang *et al.* (2007), also under FACE conditions, found lower amylose content (3.6%), decreased hardness of the rice grains, and improved palatability. However, elevated CO_2 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 per cent and 28.3 per cent, respectively). Genotype-dependent effects of elevated CO_2 on grain quality might in part explain the inconsistencies between the two above-cited studies. In any case, increased amylose concentration at warmer temperatures has been associated with increased ‘‘stickiness” of rice grains.

Lipids :

In soybean, oil content was positively correlated with increasing temperature from 25 ^{0}C to 36 ^{0}C (Wolf *et al.*, 1982). Thomas *et al.* (2003) studied the combined effects of temperature and CO_2 on the composition of soybean seeds and found that oil yield was highest at 32/22 ^{0}C (day/night) and decreased with further increase in temperature. Oleic acid concentration increased with increasing temperature, whereas linolenic acid decreased. Similar results were also obtained in sunflower. 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 any case, minimal concern for the effects of rising CO_2 on composition and edible quality, as found in maize grains and soybean seeds, has been suggested (Thomas *et al.*, 2003). 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^{0}C above ambient temperature) than on elevated CO_2 (twice above ambient CO_2). Increased temperatures had the general effect of reducing the amounts of accumulated lipids, particularly non-polar lipids (13.22 g fatty acids 1 kg fresh weight at ambient temperatures as opposed to 7.77 g fatty acids 1 kg fresh weight). In addition, unexpected qualitative changes (e.g., increased apparent conversion of oleate to linoleate) were found at higher temperatures (Williams *et al.*, 1995). Such alterations may remarkably influence the milling properties of wheat and the baking qualities of flour.

Proteins and their fractions:

Leaves of plants grown experimentally at elevated CO_2 consistently have lower levels of total N and protein. Originally this was thought to be a dilution effect from the accumulation of starch but it is now clear that less Rubisco is synthesized and that the genes controlling its production are downregulated (Gleadow *et al.*, 1998). Very recent research indicates that the ability of plants to take up nitrate (as opposed to ammonia) may also be curtailed in another, possibly independent, response (Bloom *et al.*, 2010). Less leaf protein translates into less grain protein. Lower leaf and grain protein has enormous implications for food security and animal nutrition generally but, to date, this is an under-appreciated side effect of rising CO_2. A comprehensive survey of published results showed that plants grown at ‘high N’ (it s not clear what they meant by this) on average had a 10 per cent less protein, while plants grown with limiting N had, on average, 16 per cent less protein (Taub *et al.*, 2008). The greatest impact is on grains of C_3 plants. Although those that fix nitrogen, such as soybeans, are less affected, as they have access to more nitrogen. Grains of C_4 plants such as sorghum do not seem to be much different in plants grown in different CO_2 emissions scenarios.

Taub *et al.* (2008) performed a meta-analysis (228 studies) to examine the effect of elevated atmospheric CO_2 (540–958 ppm) on the protein concentration of major food crops. For wheat, barley and rice, the reduction in grain protein ranged from 10 per cent to 15 per cent of the value of ambient CO_2 (315–400 ppm). For potato, the high-CO_2-induced reduction in tuber protein concentration was 14 per cent and, for soybean, there was a much smaller, although statistically significant, decrease in protein concentration of 1.4 per cent . It should be emphasized that nearly identical ranges in protein reduction were found using several CO_2 enrichment technologies, as shown in wheat by Högy and Fangmeier (2008). These results are particularly important because the major biotechnology companies are attempting to increase protein content in grain crops and will have to work against the effects of rising CO_2 to achieve this goal (Ainsworth *et al.*, 2008). Higher N fertilization – sometimes several times current levels – can minimize (Stafford, 2008), but not eliminate, the reduced protein concentration associated with increased atmospheric CO_2 (Taub *et al.*, 2008). It should be emphasized that fertilization at such rates would be unfeasible in terms of costs and unacceptable in terms of environmental consequences (Stafford, 2008).

Minerals :

Manderscheid (1995) studied two wheat and two barley cultivars grown in pots under ambient and two elevated CO_2 in OTCs. They found overall decreases for most macronutrients and micronutrients under high CO_2, with nutrient concentrations more affected in straw than in grains, although the responses to elevated CO_2 were species and cultivar-dependent. Idso and Idso (2001), in a qualitative narrative of several papers, suggested that more often than not high CO_2 caused decreases in leaf concentrations of essential mineral elements. Loladze (2002) performed a meta-analysis based on 25 studies covering 19 herbaceous and 11 woody species and concluded that leaf concentrations of macronutrients and micronutrients such as Fe, Zn, Mn and Cu all decreased under elevated CO_2 as compared to controls grown at ambient CO_2. Intriguingly, relatively more data concerning mineral composition exist on non staple crops than on crop species, particularly in their foliar content (Loladze, 2002). For the two major staple crops, rice and wheat, most studies suggest that, overall, decreased concentrations of nutrients, with the exception of a few minerals (see below), will be the norm in a high-CO_2 world.

In rice, Seneweera and Conroy (1997) found lower concentrations of four out of five measured elements: N (14%), P (5%), Fe (17%) and Zn (28%), but Ca increased (32%) under elevated CO_2. In wheat, Loladze (2002) 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 per cent in the concentrations of N, Ca, S, Fe, and Zn, whereas K concentration increased slightly. More recently, Högy and Fangmeier (2008) compiled existing data for mineral composition of wheat grains obtained with different CO_2 enrichment technologies and rooting volumes. They concluded that reductions in macronutrients such as N, Ca, Mg, and S were consistent for all wheat cultivars, whereas P and K responded differently to CO_2 enrichment, depending on the CO_2 exposure system and rooting volume. Högy and Fangmeier (2008) also noted high- CO_2-induced decreases in the concentrations of all micronutrients by 3.7–18.3 per cent over a range of CO_2 enrichment technologies, with the exception of Fe, which increased by 1.2 per cent (but not significantly) in closed field chambers. From the above, although detailed information regarding mineral composition of major crops is scanty, the preponderance of evidence suggests that 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 (Stafford, 2008).

Implications for summer grain crops :

At this stage it is hard to be very specific about what to expect and how to plan for the future. The good news is that all plants are likely to show improved water and nitrogen use efficiencies and to have some boost to growth in a future high-CO_2 world. C_3 plants such as sunflowers are likely to benefit the most from the CO_2-fertilisation effect. However, grain protein could be as much 15 per cent less in sunflowers. On the other hand, that may be balanced by an increase in oil yield so there may be an overall economic gain in this crop. Soybean and mungbean will also probably have less protein, but being nitrogen-fixers the effect may be less than 10 per cent. Protein in sorghum and maize grain will not change much in composition as they are C_4 plants. The negative impact on protein in grains such as wheat, rice and barley is likely to be much greater than for summer grains.

Conclusion:

Producing enough food to meet the needs of an increasing global population is one of the greatest challenges we currently face. The world needs to produce twice the amount of food using half the resources by 2050 in order to meet demand for food for a growing population and the shift towards a higher meat diet in many parts of the world. The issue of food security is further complicated by impacts of elevated CO_2, global warming and climate change. The problem is compounded by urban encroachment onto arable land and the increased costs (and potential shortages) of fertilizers. Plants are affected by rising CO_2 indirectly, through climate change and directly through the process of photosynthesis. While the climate adaptation debate has largely focused on yields, the nutritional quality of food is also fundamental. Future increases in yield must not be achieved at the expense of the nutritive value of food.

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