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Effect of Elevated CO_2 Induced High Temperature on Yield and Quality Parameters in Crops, with Preference to Tomato: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Rising CO_2 levels in the atmosphere, a major contributor to climate change, has a wide range of consequences. CO_2 can absorb and radiate heat energy resulting in the hike of earth's average temperature. The elevated CO_2-induced temperature rise in the atmosphere has a severe impact on agricultural crop productivity, as temperature is one of the important abiotic factors which influence crop growth and development. So the high temperatures and drought that accompany climate change will decrease food production and threaten food security globally.

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1. INTRODUCTION

Climate change is a global phenomenon of climate transformation especially caused by human activities and characterized by the alterations in climate patterns regarding temperature, precipitation and wind. It is a serious threat to the future of mankind and the global economy. The increase in the levels of GHGs (greenhouse gases) cause global warming [1] and climate change will ultimately cause a decline in crop yields and production. Climate change is one of the important concerns associated with India's food security challenges. It significantly affects agriculture and food production by influencing the cropping seasons [2-4] and water availability [5-7].

The current atmospheric carbon dioxide (CO_2) concentration has reached 414ppm according to NOAA, National Oceanic and Atmospheric Administration and the sixth assessment report from IPCC, Intergovernmental Panel on Climate Change gives a warning of global warming of 1.5^0 C between 2030 and 2052 [8]. The IPCC projected that there will be an increase in surface air temperature by 1.1^0C to 6.4^0C by the last of the 21^{st} century, due to increased emanations of CO_2 and other greenhouse gases into the atmosphere. So elevated CO_2 and associated high temperatures can alter the physiology and chemical composition of plants and have a direct influence on agricultural production.

Tomato is an important vegetable crop in India with an average production of 18.40 million tonnes. It is rich in antioxidants, micronutrients, phenolic compounds, carboxylic acids, vitamins and minerals. The fluctuations in environmental factors like temperature, light and water availability can drastically affect the mineral and phytochemical content in tomatoes [9]. Heat stress is a major abiotic factor that limits tomato production by influencing various physiological processes such as photosynthetic activities, transpiration, photorespiration, dark respiration as well as vegetative growth and reproductive development. Elevated temperature will cause distortion of pollen and floral structures and will impire pollen germination and further development causing decreased fruit set and yield [10]. So flowering and fruit sets are most affected under high temperature stress conditions in tomatoes.

2. EFFECT OF ELEVATED CO_2 ON OBSERVATIONS RELATED TO FLOWERING

Flowering is a critical milestone in the life cycle of plants for their reproductive success and fruit set. Since CO_2 and temperature are the key factors for plant growth and development the CO_2-induced high temperature affects various flowering-related events such as floral initiation, floral development, fruit set and fruit growth. So climate change has a significant impact on flowering-related events in plants. Addressing the effects of these environmental factors on the time of anthesis and flowering time is critical to understanding the adaptation of plants/ crops to climate change.

Elevated CO_2 and increasing ambient temperature is a major climatic factor that advances flowering time in certain crops. It reported an increase in the flower number under increased CO_2 condition [11]. An experiment reported that the increased number of flowers and fruits together with higher fruit sets led to higher fruit yield at EC concentrations (EC 550 and 700 ppm) [12]. It is reported that plants grown under high CO_2 reached flowering 8 days sooner than those grown under ambient conditions [13].

3. POLLEN VIABILITY

The impaired pollen development and reduced pollen viability will decrease the yield of crops at high temperatures. Elevated CO_2 and associated heat stress at meiosis reduced pollen viability, spikelet number and grain yield per spike in wheat [14]. It showed that the pollen viability of quinoa has reduced between 30% and 70% under heat stress [15]. Continuous exposure of tomatoes to high temperatures reduced the number of pollen grains per flower and decreased viability because of the alterations in carbohydrate metabolism in various parts of the anther during its development [16]. It reported that the CO_2 enrichment and associated high temperature had a negative effect on pollen viability of green gram due to degeneration of the tapetum layer [17]. Pollen viability was found to be the least (8.37% decrease) under elevated CO_2 conditions compared to control conditions in pea plants [18]. The heat stress during male reproductive development reduces pollen viability and function [19].

4. POLLEN MORPHOLOGY

During plant development, the important heat-sensitive stage is the pollen development [20]. It is reported that high-temperature stress due to elevated CO_2 will negatively affect the pollen development [21]. Pollen produced by flowers in soybeans grown under elevated CO_2 conditions appeared shrivelled without apertures and with disturbed exine orientation [22]. In quinoa, the heat stress increased the pollen wall thickness [23]. The pollen of soybean flowers appeared shrivelled without apertures and with disturbed exine ornamentation at elevated CO_2 conditions [24]. High temperature stress leads to disruption of meiotic cell division, and abnormal pollen morphology and size [25].

5. EFFECT OF ELEVATED CO_2 ON YIELD PARAMETERS

The high CO_2 concentration increases the photosynthetic rate and yield of crops. It is reported that the beneficial effects of CO_2 enrichment on the yield of tomatoes by increasing the no of flowers and fruits per plant [26]. However, the higher temperature can negatively affect the tomato yield. In an experiment on the combined effects of CO_2 and the temperature on the grain yield, it is observed that a temperature of 27^0C or higher applied mid-way through anthesis could result in a high number of sterile grains and resulted in considerable yield losses [27]. An increased number of flowers and fruits together with a higher fruit set leading to higher fruit yield in tomatoes was observed at elevated CO_2 conditions (700 ppm and 500 ppm) compared to the control condition, the, highest yield being obtained under 700 ppm of CO_2 [28]. It is reported that the increase in average daily temperatures of 25-29^0C will decrease the fruit set percentage, number of fruits and fruit weight per plant in tomato [29]. A reduction in fruit set and delays in fruit colour development at temperatures above 35^0C [30].

6. EFFECT OF ELEVATED CO_2 ON QUALITY PARAMETERS

In vegetables, the elevated CO_2 concentration improves yield but it decreases the nutritional quality. In the meta-analysis of vegetables, it is concluded that the concentration of fructose, glucose, TSS, phenols, total flavanoids, vitamin C and calcium increased in the edible part of vegetables but the concentrations of protein, nitrate, magnesium, iron and zinc get decreased [31]. At the same time elevated CO_2 did not have any effect on titratable acidity, total chlorophyll, carotenoids, lycopene, anthocyanin, potassium, phosphorus, sulphur, copper and manganese. It is reported the the positive effect of elevated CO_2 on quality parameters such as TSS, total sugars, total reducing sugars and ascorbic acid contents of tomato fruits, but the CO_2 concentration above 700ppm caused a reduction [32]. It is reported that the chickpea seeds harvested from high CO_2 conditions showed a reduced seed protein (7%), total phenol (13%) and thiobarbituric acid reactive substances (12%) and increased starch content (21%) and water uptake rate as compared to seed harvested from ambient CO_2 condition [33]. It is reported that the quality parameters of tomato fruit such as ascorbic acid, carotene, and lycopene were improved at 550ppm and decreased at 700ppm. But at 550 ppm, the antioxidant capacity and flavonoids were found to get decreased [34].

7. CONCLUSION

Climate change has become the focus of social and scientific attention. The increase in carbon dioxide (CO_2) in the atmosphere is one of the most visible and undesirable indicators of global climate change. In vegetables, especially in tomatoes, the increased CO_2 concentration improves yield but reduces quality. Many research efforts focus on these stresses to shield the plants from harmful circumstances. The plants need to be given the best circumstances for growth at each stage. Germination, vegetative stage, reproductive stage, and yield are all impacted by high-temperature stress and it is critically necessary to find innovative ways to adapt crops to these changes.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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