

Review Article

Effect of elevated CO₂ and induced high temperature on flowering and fruiting in crops, with preference to tomato: - A review

ABSTRACT

Rising CO₂ levels in the atmosphere, a major contributor to climate change, has a wide range of consequences. CO₂ can absorb and radiate heat energy resulting in the hike of earth's average temperature. The elevated CO₂ induced temperature rise in 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 temperature and drought that accompany climate change will decrease the food production and threaten food security globally.

Keywords: Climate change, Elevated CO₂, Flowering, Fruiting, Tomato

Introduction

Climate change is a global phenomenon of climate transformation especially caused by human activities and characterized by the alterations in climate pattern regarding temperature, precipitation and wind. It is a serious threat to future mankind and global economy. The increase in the levels of GHGs (greenhouse gases) will cause global warming (Sundaret al., 2021) and the climate change will ultimately cause a decline in crop yields and productions. 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 (Fiwaet al., 2014; Zhao et al., 2015; Lemma et al., 2016) water availability (Lobellet al., 2015; Saadiet al., 2015; Schaubbergeret al., 2017)

The current atmospheric carbon dioxide (CO₂) concentration has reached 414 ppm according to NOAA and the sixth assessment report from IPCC gives a warning of global warming of 1.5^o C between 2030 and 2052 (IPCC, 2021). The IPCC projected that there will be an increase in surface air temperature by 1.1^oC to 6.4^oC by last of the 21st century, due to increased emanations of CO₂ and other greenhouse gases into the atmosphere. So elevated CO₂ and associated high temperature can alter the physiology and chemical composition of plants and have 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 tomato (Nouret al., 2013). 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 impair pollen germination and further development causing decreased fruit set and yield (Sato et al., 2000). So flowering and fruit set are most affected under high temperature stress conditions in tomato.

Comment [A1]: As I have read your article, the rising CO₂ concentration has its own direct effect as well as indirect consequence on the anthesis and fruiting in crops through high temperature. So, it is better to discuss the effect of CO₂ concentration and high temperature separately.

Comment [A2]: Please state the objective of this paper.

Comment [A3]: What NOAA mean?

Comment [A4]: What IPCC mean? Please define it.

Comment [A5]: Dear author, please follow the journal's template and guideline in writing your manuscript.

Effect of elevated CO₂ on observations related to flowering

Flowering is a critical milestone in the lifecycle of plants for its reproductive success and fruit set. Since CO₂ and temperature are the key factors for plant growth and development, the CO₂-induced high temperature affects various flowering related events such as floral initiation, floral development, fruit set and fruit growth. So the climate change has a significant impact on flowering related events in plants. Addressing the effects of these environmental factors on time of anthesis and flowering time is critical to understand the adaptation of plants/crops to climate change.

Elevated CO₂ and increasing ambient temperature is a major climatic factor that advances flowering time in certain crops. Rangaswami *et al.* (2021) reported an increase in the flower number under increased CO₂ condition. An experiment conducted by Mamatha *et al.* (2014) reported that the increased number of flowers and fruits together with higher fruit set led to higher fruit yield at EC concentrations (EC 550 and 700 ppm). It is reported that plants grown under high CO₂ reached flowering 8 days sooner than those grown under ambient condition (Lanoue *et al.*, 2018).

Pollen viability

The impaired pollen development and reduced pollen viability will decrease the yield of crops at high temperature. Elevated CO₂ and associated heat stress at meiosis reduced pollen viability, spikelet number and grain yield per spike in wheat (Bokshi *et al.*, 2021). Hinojosa *et al.*, (2019) showed that the pollen viability of quinoa has reduced between 30% and 70% under heat stress. Continuous exposure of tomato to high temperature 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 (Pressman *et al.*, 2002). Suzuki *et al.* (2001) reported that the CO₂ enrichment and associated high temperature had a negative effect on pollen viability of green gram due to degeneration of tapetum layer. Pollen viability was found to be the least (8.37% decrease) under elevated CO₂ conditions compared to control conditions in pea plants (Kumari *et al.*, 2016). The heat stress during male reproductive development reduces pollen viability and function (Muller and Rieu, 2016).

Pollen morphology

During plant development, the important heat sensitive stage is the pollen development (Lohan *et al.*, 2020). Kumari *et al.*, (2016) reported that high temperature stress due to elevated CO₂ will negatively affect the pollen development. Pollen produced by flowers in soybean grown under elevated CO₂ conditions appeared shriveled without apertures and with disturbed exine orientation (Kotiet *et al.*, 2004). In quinoa, the heat stress increased the pollen wall thickness (Hinojosa *et al.*, 2019). The pollen of soybean flowers appeared shriveled without apertures and with disturbed exine ornamentation at elevated CO₂ conditions (Kotiet *et al.*, 2005). High temperature stress leads to disruption of meiotic cell division, abnormal pollen morphology and size (Begcyet *et al.*, 2019).

Effect of elevated CO₂ on yield parameters

The high CO₂ concentration increases the photosynthetic rate and yield of crops. Rangaswamy *et al.* (2021) reported the beneficial effects of CO₂ enrichment on yield of tomato by increasing the no of flowers and fruit per plant. But the higher temperature can negatively affect the tomato yield. In an experiment on the combined effects of CO₂ and the temperature on the grain yield, Hemantaranjan *et al.* (2014) observed that a temperature of 27°C or higher applied mid way through anthesis could result in a high number of sterile grains and resulted in considerable yield losses. Increased number of flowers and fruits together with higher fruit set leading to higher fruit yield in tomato was observed at elevated CO₂ condition (700 ppm and 500 ppm) compared to control condition, the highest yield being obtained under 700ppm of CO₂ (Mamata *et al.*, 2014). Hare *et al.*, (2014) reported that the increase in average daily temperatures of 25-29°C will decrease the fruit set percentage, number of fruits and fruit weight per plant in tomato. Sato *et al.*, (2006) reported a reduction in fruit set and delay in fruit color development at temperature above 35°C.

Effect of elevated CO₂ on quality parameters

In vegetables, the elevated CO₂ concentration improves yield but it decreases the nutritional quality. In the metaanalysis of vegetables, Dong *et al.* (2018) concluded that the concentration of fructose, glucose, TSS, phenols, total flavanoids, vitamin C and calcium increased in edible part of vegetables but the concentrations of protein, nitrate, magnesium, iron and zinc get decreased. At the same time elevated CO₂ did not have any effect on titratable acidity, total chlorophyll, carotenoids, lycopene, anthocyanin, potassium, phosphorus, sulphur, copper and manganese. Rangaswamy *et al.*, 2021 reported the positive effect of elevated CO₂ on quality parameters such as TSS, total sugars, total reducing sugars and ascorbic acid contents of tomato fruits, but the CO₂ concentration above 700 ppm caused a reduction. Lamichan *et al.*, 2021 reported that the chickpea seeds harvested from high CO₂ condition 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 CO₂ Condition. Mamatha *et al.* (2014) reported that the quality parameters of tomato fruit such as ascorbic acid, carotene, lycopene improved at 550ppm and decreased at 700 ppm. but at 550 ppm, the antioxidant capacity and flavonoids were found decreased.

CONCLUSION

Climate change has become the focus of social and scientific attention. The increase in carbon dioxide (CO₂) in the atmosphere is one of the most visible and undesirable indicators of global climate change. In vegetables, especially in tomato, the increased CO₂ 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 the yield are all impacted by high temperature stress and it is critically necessary to find innovative ways to adapt crops to these changes.

ETHICAL APPROVAL

This article does not contain any studies with human participants or animals performed by any of the authors.

Comment [A6]: These two sentences indicate the significance of discussing the effects of CO₂ and high temperature separately.

Comment [A7]: It's better that your literature divided into two sections
 2. Effect of elevated CO₂ and high temperature on flowering and fruiting in crops

- 2.1. Effect of elevated CO₂ on flowering and fruiting in crops
 - 2.1.1. Number of flowers and flowering time
 - 2.1.2. Pollen viability and morphology
 - 2.1.3. Yield parameters
 - 2.1.4. Quality parameters

- 2.2. Effect of elevated CO₂-induced high temperature
 - 2.2.1.
 - 2.2.2.
 and so on.

Comment [A8]: Dear author your title only tells us about the effect of high temperature on flowering and fruiting of crops, not about other yield parameters and quality parameters. So, you need to modify either your title or the body of your article.

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