Effect ofelevated CO_2 induced high temperatureon yield and quality parameters in crops, with preferencetotomato: A review

ABSTRACT

Rising CO2 levels in theatmosphere, a major contributor toclimate change, has a wide range of consequences. CO_2 can absorb and radiate heat energyresulting in the hike of earth's averagetemperature.Theelevated CO_2-induced temperature rise in the atmosphere has a severeimpact on agricultural crop productivity, as temperature isone of the important abiotic factors whichinfluence cropgrowth anddevelopment. Sothe high temperatures and drought that accompany climate change will decrease foodproduction and threatenfood security globally.

Keywords: Climate change,Elevated CO_2,Flowering,Fruiting, Tomato

INTRODUCTION

Climatechangeisa global phenomenonof climate transformationespeciallycaused by human activities andcharacterized by thealterations in climate pattern regarding temperature, precipitationandwind. Itis aserious threatto futureof mankindandthe global economy. The increase in the levels of GHGs(greenhousegases) willcause global warming [1] and climatechange will ultimately cause a decline in crop yields and production. Climate changeis oneof theimportant concerns associated with India's food security challenges. It significantly affects agriculture and food production by influencing the cropping seasons[2][3][4]and water availability[5][6][7].

The currentatmosphericcarbon dioxide(CO_2) concentrationhas reached 414ppm accordingto NOAA, National Oceanic and Atmospheric Administrationand thesixth assessmentreport from IPCC,Intergovernmental Panel on Climate Change gives a warning of globalwarming of 1.5^0 C between 2030 and 2052[8]. TheIPCC projected that there will be anincrease in surfaceair temperature by 1.1^0C to 6.4^0C by the last of the 21^{st} century, due to increasedemanations of CO_2 and othergreenhouse gases intothe atmosphere. Soelevated $CO_2$and associatedhigh temperatures can alterthe physiology andchemical compositionof plants andhave a directinfluence on agriculturalproduction.

Tomatois an importantvegetablecrop in Indiawith an averageproduction of 18.40 milliontonnes. It isrich in antioxidants, micronutrients,phenoliccompounds, carboxylic acids,vitamins and minerals.The fluctuations in environmental factors like temperature, lightand water availability can drasticallyaffect the mineral and phytochemical content in tomatoes [9]. Heatstress is a major abioticfactor that limits tomato production byinfluencing various physiological processes such as

photosynthetic activities, transpiration, photorespiration, darkrespiration aswell as vegetativegrowth and reproductivedevelopment. Elevated temperaturewill causedistortion ofpollenandfloralstructures and willimpirepollen germinationand furtherdevelopment causingdecreased fruit set andyield [10]. So floweringand fruitsets are most affected underhigh temperature stressconditions intomatoes.

Effectof elevated CO_2 on observationsrelated toflowering

Floweringis a criticalmilestone in thelife cycleof plants for their reproductive successandfruitset. Since CO_2andtemperature are thekey factors forplantgrowth and developmentthe CO_2-inducedhigh temperatureaffects various flowering-relatedevents such as floral initiation, floraldevelopment,fruit set and fruit growth.So climatechange has a significantimpact onflowering-relatedevents in plants.Addressing the effects of these environmentalfactors on the timeofanthesis andflowering time is criticaltounderstanding the adaptationof plants/ cropsto climatechange.

ElevatedCO_2 and increasingambient temperature isa major climaticfactor that advances floweringtime incertain crops. It reportedan increase in the flower numberunder increased CO_2 condition[11]. Anexperiment reported thatthe increased numberof flowers and fruits togetherwith higher fruit sets led to higher fruit yield at ECconcentrations (EC 550 and 700 ppm)[12]. It isreported that plants grown under high CO_2reached flowering 8 dayssooner than those grownunder ambientconditions [13].

Pollen viability

Theimpairedpollen developmentand reducedpollen viabilitywill decrease the yieldof crops at hightemperatures.ElevatedCO_2andassociated heatstress at meiosis reduced pollen viability,spikelet numberand grain yieldper spike inwheat[14]. It showedthat the pollenviabilityofquinoa has reduced between 30% and 70% underheat stress [15]. Continuousexposure of tomato to high temperatures reduced thenumber ofpollen grains per flowerand decreasedviability because of thealterations in carbohydratemetabolism in various parts of theanther during itsdevelopment[16]. It reported that the CO_2 enrichmentand associatedhigh temperature had anegative effecton pollen viabilityof green gramdue to degenerationof the tapetum layer[17]. Pollenviability was found tobe theleast (8.37% decrease) under elevated CO_2 conditions comparedto controlconditions in pea plants[18]. Theheat stress duringmale reproductivedevelopment reducespollen viability and function[19]

Pollen morphology

Duringplantdevelopment,theimportant heat-sensitivestage is thepollen development[20]. It is reported that high-temperature stress due to elevated CO_2 will negativelyaffect the pollendevelopment[21]. Pollenproduced by flowers in soybean grown underelevated CO_2 conditions appeared shrivelled withoutapertures and with disturbed exine orientation [22]. In quinoa, theheat stress increasedthe pollen wall thickness[23].The pollen of soybeanflowers appeared shrivelledwithout apertures and withdisturbed exine ornamentationat elevated CO_2conditions[24].

High temperaturestress leads todisruption of meioticcell division, and abnormalpollen morphology andsize [25].

Effect of elevated CO_2 on yield parameters

Thehigh CO_2concentrationincreases thephotosyntheticrate and yield of crops. It is reported thatthe beneficial effectsof CO_2 enrichment on the yield of tomatoes by increasing the no of flowers and fruit perplant[26]. However, the higher temperature can negativelyaffectthe tomato yield. In anexperiment on the combined effects of CO_2 and the temperature on the grainyield, it is observed that atemperature of 27^0C or higherappliedmid-way throughanthesiscouldresult in a high number of sterile grains and resulted inconsiderable yield losses[27]. An increasednumber offlowers and fruits together with a higher fruitset leading tohigher fruit yield intomatoes was observed at elevated CO_2 conditions (700 ppm and 500 ppm) comparedto the controlcondition, the highest yield beingobtained under 700 ppm of CO_2 [28]. It is reported that the increase in average daily temperatures of 25-29^{0}C will decrease the fruit setpercentage, numberof fruits and fruit weightper plant in tomato[29]. reduction in fruitsetand delays in fruit colour development attemperature above 35^0C[30].

Effectof elevated CO_2 on qualityparameters

In vegetables, the elevated CO_2concentrationimprovesyield but it decreases the nutritional quality. In themeta-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 concentrationsof protein, nitrate, magnesium, iron and zincget decreased[31]. Atthe sametime elevated CO_2 didnot have any effect on titratable acidity, total chlorophyll, carotenoids, lycopene, anthocyanin, potassium, phosphorus, sulphur, copper andmanganese. It is reported thethepositive effect of elevated CO_2 on quality parameterssuch asTSS, total sugars, totalreducing 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%), totalphenol(13%) and thiobarbituric acid reactivesubstances (12%) andincreased starch content (21%)and wateruptake rate ascompared to seed harvested from ambient CO_2 Condition[33]. It is reported that thequality parametersof tomato fruit such as ascorbicacid, carotene, and lycopeneimproved at 550ppm and decreased at 700ppm. but at 550 ppm, the antioxidantcapacity and flavonoidswere foundto decrease [34].

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 tomatoes, the increased CO_2 concentration improves yield but reduces quality.Manyresearch efforts focus on these stressesto shieldthe plants from harmfulcircumstances. The plants need to be giventhe best circumstancesfor growth at each stage. Germination,vegetative stage, reproductive stage, and yield are all impacted by high-temperature stressand it is critically necessary tofind innovative ways to adapt crops to these changes.

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REFERENCES

[1] Sundar LS, Mesfin S, Said Z, Singh MK, Punnaiah, V. and Sousa AC. Energy, Economic,Environmental and heat transfer analysis of a solar flat plate collector with Ph treated Fe 3 O 4/water nanaofluid. International Journal of Energy for a Clean Environment.2021.22(6): 55-98.

[2] Fiwa L, Vanuytrecht E, Wiyo, KA, Raes D.Effect of rainfall variability on the length of the crop growing period over the past three decades in central Malawi. Climate Research.2014.62(1):45-58.

[3] Zhou R, Yu X, Kjær KH, Rosenqvist E, Ottosen CO. and Wu, Z. Screening and validation of tomato genotypes under heat stress using Fv/Fm to reveal the physiological mechanism of heat tolerance. Environmental and Experimental Botany.2015 118: 1-11.

[4] Lemma S, Sboarina M, Porporato PE, Zini N, Sonveaux, P, Di Pompo G, Baldini, N, Avnet, S. 2016. Energy metabolism in osteoclast formation and activity. The international journal of biochemistry & cell biology.2016. 79: 168-180

[5] Lobell DB, Hammer GL, Chenu K, Zheng B, Mc Lean G and Chapman SC. The shifting influence of drought and heat stress for crops in northeast Australia. Global change biology.*2015*. 21(11): 4115-4127.

[6] Saadi S, Todorovic M, Tanasijevic L, Pereira LS, Pizzigalli C, Lionello, P. Climate change and Mediterranean agriculture: Impacts on winter wheat and tomato crop evapotranspiration, irrigation requirements and yield. Agricultural water management.2015. 103-115.

[7] Schauberger B, Archontoulis S, Arneth A, Balkovic J, Ciais P, Deryng D, Elliott J, Folberth C, Khabarov N, Müller C. and Pugh TA. 2017. Consistent negative response of US crops to high temperatures in observations and crop models. Nature communications.2017.8(1): pp.1-9.

[8] IPCC. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.2021.

[9] Nour M, Berean K, Balendhran S, Ou, JZ, Du Plessis J, Mc Sweeney C, Bhaskaran M, Sriram, S. and Kalantar-zadeh K. CNT/PDMS composite membranes for H2 and CH4 gas separation. International Journal of Hydrogen Energ.2013.38(25): 10494-10501.

[10] Sato S, Peet MM and Thomas JF. Determining critical pre-and post-anthesis periods and physiological processes in *Lycopersicon esculentum Mill*. exposed to moderately elevated temperatures. Journal of Experimental Botany, 2000.53(371): 1187-1195.

[11] Rangaswamy TC, Sridhara S, Ramesh N, Gopakkali P, El-Ansary DO, Mahmoud EA, Abdelmohsen SA, Abdelbacki AM, Elansary HO, Abdel-Hamid AM. 2021. Assessing the Impact of Higher Levels of CO_2 and Temperature and Their Interactions on Tomato (*Solanum lycopersicum L*.). Plants.2021, 10 (2):256.

[12] Mamatha H, Rao NS, Laxman RH, ShivashankaraKS, Bhatt RM, Pavithra KC. Impact of elevated CO_2 on growth, physiology, yield and quality of tomato (*Lycopersicon esculentum Mill*) cv. Arka Ashish. Photosynthetica.2014. 52(4): 519-528.

[13] Lanoue J, Leonardos ED, Khosla S, Hao X,Grodzinski B. Effect of elevated CO_2 and spectral quality on whole plant gas exchange patterns in tomatoes. PloS one. 2018.13(10), p.e0205861.

[14] Bokshi AI, Tan DK, Thistlethwaite RJ,Trethowan R and Kunz K. Impact of elevated CO2 and heat stress on wheat pollen viability and grain production. Functional Plant Biology.2021, *48*(5):503-514.

[15]Hinojosa L, Matanguihan JB and Murphy KM. Effect of high temperature on pollen morphology, plant growth and seed yield in quinoa (*Chenopodium quinoa Willd*.). *J. of agron. and crop sci*. 2019.205(1): 33-45.

[16] Pressman E, Peet MM, Pharr DM. The effect of heat stress on tomato pollen characteristics is associated with changes in carbohydrate concentration in the developing anthers. Ann. of bot.2002.90(5): 631-636.

[17] Suzuki K, Takeda H, Tsukaguchi T, Egawa Y. Ultrastructural study on degeneration of tapetum in anther of snap bean (*Phaseolus vulgaris L*.) under heat stress. Sexual Plant Reproduction.2002. 13(6): 293-299.

[18] Kumari M, Verma SC, Bhardwaj SK, Thakur AK, Gupta RK, Sharma R. Effect of elevated CO_2 and temperature on growth parameters of pea (*Pisum sativum L*.) crop. J. of Appl. and Nat. Sci*.* 2016*,* 8(4): 1941-1946.

[19] Müller F, Rieu I. Acclimation to high temperature during pollen development. Plant Reproduction. 2016.29(1): 107-118.

[20] Lohani N, Singh MB and Bhalla PL. High temperature susceptibility of sexual reproduction in crop plants. J. of exp.bot. 2020.71(2): 555-568.

[21]Kumari M, Verma SC, Bhardwaj SK, Thakur AK, Gupta RK, Sharma R.. Effect of elevated CO_2 and temperature on growth parameters of pea (Pisum sativum L.) crop. J. of Appl. and Nat. Sci.2016. 8(4): 1941-1946.

[22] Koti S, Reddy KR, Kakani VG, Zhao D, Reddy VR. 2004. Soybean (*Glycine max*) pollen germination characteristics, flower and pollen morphology in response to enhanced ultraviolet-B radiation. Ann. of bot., 94(6): 855-864.

[23] Hinojosa L, Matanguihan JB and Murphy KM. 2019. Effect of high temperature on pollen morphology, plant growth and seed yield in quinoa (*Chenopodium quinoa* Willd.). J. of agron. and crop sci., 205(1): 33-45

[24] Koti S, Reddy KR, Reddy VR, Kakani VG, Zhao D. 2005. Interactive effects of carbon dioxide, temperature, and ultraviolet-B radiation on soybean (*Glycine max* L.) flower and pollen morphology, pollen production,germination, and tube lengths. J. of experimental bot., 56(412): 725-736.

[25]Begcy K, Nosenko T, Zhou LZ, Fragner L, Weckwerth W and Dresselhaus T. 2019. Male sterility in maize after transient heat stress during the tetrad stage of pollen development. Plant physiol., 181(2): 683-700.

[26] Rangaswamy TC, Sridhara S, Ramesh N, Gopakkali P, El-AnsaryDO, Mahmoud EA, Abdelmohsen SA, Abdelbacki AM, Elansary HO, Abdel-Hamid AM. 2021. Assessing the Impact of Higher Levels of CO_2 and Temperature and Their Interactions on Tomato (*Solanum lycopersicum* L.). Plants., 10 (2):256.

[27] Hinojosa L, Matanguihan JB and Murphy KM. 2019. Effect of high temperature on pollen morphology, plant growth and seed yield in quinoa (*Chenopodium quinoa Willd*.). J. of agron. and crop sci., 205(1): 33-45

[28] Mamatha H. Rao NS, Laxman RH, Shivashankara KS, Bhatt RM, Pavithra KC. 2014. Impact of elevated CO_2 on growth, physiology, yield,and quality of tomato (*Lycopersicon esculentum* Mill) cv. Arka Ashish. Photosynthetica., 52(4): 519-528.

[29] Harel D, Fadida H, Slepoy A, Gantz S, Shilo K. 2014. The effect of mean daily temperature and relative humidity on pollen, fruit set and yield of tomato grown in commercial protected cultivation. Agronomy., 4(1): 167-177.

[30] Sato S, Kamiyama M, Iwata T, Makita N, Furukawa H and Ikeda H. 2006.

[31] Dong J, Gruda N, Lam SK, Li X. and Duan Z. 2018. Effects of elevated CO_2 on nutritional quality of vegetables: a review. Frontiers in plant Sci., p.924.

[32]Rangaswamy TC, Sridhara S, Ramesh N, Gopakkali P, El-Ansary DO, Mahmoud EA, Abdelmohsen SA, Abdelbacki AM, Elansary HO, Abdel-Hamid AM. 2021. Assessing the Impact of Higher Levels of CO_2 and Temperature and Their Interactions on Tomato (*Solanum lycopersicum* L.). Plants., 10 (2):256

[33] Lamichaney A, Tewari K, Basu PS, Katiyar PK, Singh NP. 2021. Effect of elevated carbon-dioxide on plant growth, physiology, yield and seed quality of chickpea (*Cicer arietinum* L.) in Indo-Gangetic plains. Physiol. and Mole. Biol. of Plants, 27(2): 251-263.

[34]Mamatha H, Rao ZS, Laxman RH, Shivashankara KS, Bhatt RM, Pavithra KC. 2014. Impact of elevated CO_2 on growth, physiology, yield,and quality of tomato (Lycopersicon esculentum Mill) cv. Arka Ashish. Photosynthetica., 52(4): 519-528.