



Environment, Biodiversity & Soil Security (EBSS)

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Management of Heat Stress in Tomato Seedlings under Arid and Semi-Arid Regions: A Review



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THE production of protected cultivation of vegetables could be considered as a sustainable solution in arid and semi-arid regions. These regions already suffer from raising temperature and the global warming will aggravate this, which represents a great challenge facing our universe nowadays. Hence, the production of vegetables and tomato under greenhouse system during the high temperatures may be considered a serious problem should be avoided in these arid zones in summer due to heat stress. The heat stress may cause a lot of troubles for the tomato seedlings in greenhouses in summer starting with the photosynthetic rate, and the metabolism processes in seedlings and in turn the growth and development of these seedlings. Although studies have recognized heat stress on tomato seedlings, research has yet to systematically investigate the effect of heat stress on tomato seedlings in greenhouse in summer under arid and semi-arid regions particularly in developing countries, which their greenhouses have not any climate controllers. Therefore, the management of tomato seedlings may need to address the production problems caused by heat stress in greenhouse conditions particularly in arid and semi-arid zones

Keywords : High temperature stress, Abiotic stress, Protected agriculture, Greenhouse.

Introduction

Climate change and global warming are serious problems threatening the agricultural production. The global temperature is projected to increase with a rate may reach 1.5 and 3.5°C by 2050 and 2100, respectively (Zhou et al., 2020). The high temperature or heat stress is considered one of the most devastating abiotic stresses, which becomes more serious due to the global warming (Bilal et al. 2020). High temperature stress may disturb cellular homeostasis, affects physiological and biochemical reactions, as a consequence, impedes plant growth, development and eventually reduces crop productivity (Fahad et al., 2017).

Due to many environmental problems, the protected cultivation has established to overcome these problems. It could be defined the protected agriculture or cultivation as a group of agricultural practices, which allows to produce the cultivated crop in plastic- or glass-house to protect plants from climatic conditions and pests (Nordey et al. 2017 and Ghani et al., 2019). This protected cultivation could be considered as a “sustainable solution” in producing the foods particularly in hot-arid environments (Ghani et al., 2019).

Tomato (*Solanum lycopersicum* L.) is considered a popular vegetable belongs to the family Solanaceae. This crop could widely grow and consume across

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Received 17/04/2020; Accepted 4/06/2020

DOI: 10.21608/jenvbs.2020.28143.1089

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the world. Due to its high nutritional value, tomato is considered the second favored and consumed vegetable crop after potato in the world (Siddiqui *et al.*, 2020). Tomato fruits have the abundant nutrients (*e.g.*, copper, selenium, manganese and zinc), antioxidants (lycopene and β -carotene), active components (*e.g.*, poly-phenols and carotenoids), nutritional organic acids (ascorbic, citric and malic acid) and vitamins like C, E and A (Singh *et al.*, 2018). The tomato fruit is called “*the poor man’s orange*” because these fruits are rich in vitamin C, malic and citric acids as well as its low price (Alsuhaibani, 2018). The global production of tomato was estimated to be approximately 182 million tons in 2017 (FAOSTAT, 2019). The cultivation and production of tomato may decrease due to the stress of unfavorable climatic conditions or climate changes and the imbalance supply of nutrients (Naz *et al.*, 2019 and Siddiqui *et al.*, 2020). This stress may affect different biochemical and physiological parameters of tomato plants. Under the arid and semi-arid conditions, tomato may face multiple stresses including drought and heat stress. Concerning the impact of high temperature on tomato, it is reported that the tomato growth may be impeded during the summer period threatening the yield (Zhou *et al.*, 2020).

The global production of tomato, like other cultivated crops, face many challenges particularly the biotic (*i.e.*, plant pathogens including bacteria, fungi, nematodes and viruses) and abiotic stresses (*e.g.*, salinity, drought, waterlogging, chilling and heat stress). Different physiological, biochemical, morphological and molecular changes represent the response of cultivated plants to the environmental challenges, which adversely lead to decrease the plant growth and its productivity (Zandalinas *et al.*, 2018). Thus, these previous stresses cause direct and indirect reduction in the growth and yield of tomato (Singh *et al.*, 2018). Under changing climate and global warming, the heat stress could be considered one of the most important stresses limiting tomato productivity beside drought and salinity particularly in arid and semi-arid zones. It is worth mentioning that, the abiotic stress in agroecosystems could be mediated by nanomaterial (Elsakhawy *et al.*, 2018), seeking for the sustainable irrigation and fertilization (Amer *et al.*, 2019) and plant nutrition (El-Ramady *et al.*, 2020).

Therefore, this review aimed to address the heat stress as a global issue and its impact on tomato seedlings production. The protected tomato seedlings under heat stress in the greenhouse in

arid and semi-arid zones and its management also will be discussed.

Tomato as a Model Plant

Tomato (*Solanum lycopersicum* L.) is considered a popular vegetable worldwide. This Solanaceous seedling has categorized as an important model plant in investigating the stress tolerance (Zhang *et al.*, 2018). So, several stress studies have been carried on tomato seedlings such as heat stress (Lyu *et al.*, 2018), water stress (Zhang *et al.*, 2018), drought (Bian *et al.*, 2019), salinity (Zhou *et al.*, 2019), UV-B stress (Liu *et al.*, 2020), chilling (Dong *et al.*, 2020), and waterlogging (Elkelish *et al.*, 2020). Many strategies could be adapted to overcome these stresses depending on the kind of stress, cultivated plants and its growth stage (Zhou *et al.*, 2020). Several researchers reported about these strategies for tomato seedlings, which include the application of spermidine (Sang *et al.*, 2016), Ca, Mg and K compounds (Sakhonwasee and Phingkanan, 2017 and Nafees *et al.*, 2019), ascorbic acid (Alayafi, 2019), melatonin and salicylic acid (Jahanet *et al.*, 2019, 2020b) as well as proline (Tonhati *et al.*, 2020). Therefore, the production of tomato seedlings under greenhouse conditions may face some stresses, which still need more and more investigations in particular in arid and semi-arid regions in summer (Fig. 1). To what extend how the greenhouse could guarantee the highest yield of tomato for a long time under heat stress in arid zones? To what extend how heat stress could increase soil salinization and its degradation during tomato seedlings production in arid zones? To what extend how the greenhouse could support the tomato seedlings production in summer in arid zones?

Protected Cultivation of Tomato Seedlings and Stress

It could be defined the “*protected agriculture*” as a cropping technique, by which the micro-environment surrounding the cultivated plants could be controlled partially or fully modify during their period of growth to maximize the productivity (Nordey *et al.*, 2017). The protected cultivation has a great potential in increasing the productivity of vegetables (*e.g.*, pepper, tomato, strawberry, cucumber and green beans) and flower crops (*e.g.*, rose, gerbera, orchid, chrysanthemum and carnation) by several folds (Reddy 2016). This protected agriculture has several advantages particularly in arid and semi-arid zones such as (1) a high yield in greenhouse comparing with open field, (2) a high protection from dis-

eases and pests as well as undesirable climatic conditions, (3) the possibility to cultivate crops during off-season compared with the open fields, and (4) the excellent opportunity to produce in high quality crops for exportation in greenhouses (Reddy, 2016). The use of greenhouse in arid and semi-arid zones has been the subject of intense debate within the scientific community due to its many environmental problems and economic benefits as well. The environmental problems may result from the long-term production of vegetable, intensive use of fertilizers and irrigation under greenhouse conditions in arid and semi-arid leading to soil pollution and degradation and gas emissions as well (Liang et al., 2013; Sun et al., 2018 and Shurpali et al., 2019).

Due to the rapid growth in populations, the dramatic fluctuations in atmospheric temperature and the limited sources of arable lands, the greenhouses are considered intensive tools of agriculture, which have been widely applied worldwide (Sun et al., 2018). Under greenhouse conditions, daily fluctuations in both temperature and light could control the growth of plants creating biotic and abiotic stresses. The fluctuations in essential mineral nutrients bioavailability could be mainly influenced by the soil physico-chemical properties and their biological activities (Bouain et al., 2019). Therefore, the production of tomato seedlings in the greenhouse could be maximized in winter but in summer may face a heat stress in arid and semi-arid.

The production of tomato seedlings in the greenhouse mainly is controlled by many factors like the right applied source, rate, time and place of nutrients. Nutrients are considered the key factor in the growth of plants and development, which their bioavailability in the rhizosphere mainly regulate the plant biomass and productivity (Pandey et al., 2020). The overdose of these nutrients may be represented as a real threat causing nutrient stress in production of tomato seedlings (Table 1). The response of tomato seedlings towards the nutrient stress may depend on the growth conditions, anti-stress used and its recommended dose (Table 1). There are several anti-stress could be applied to mitigate the abiotic stress on cultivated plants (e.g., nitric oxide, abscisic acid, melatonin, gibberellins and kinetin). The role of anti-stress in mitigation of the nutrient stress of tomato seedlings could be handled in the following sub-sections.

Nitric oxide (NO) is "redox-related signaling molecule" and a "gaseous free radical", which could regulate the growth of plants and its

development (Gupta et al., 2019). This molecule also could support cultivated plants against abiotic stress because NO can regulate a lot of proteins activity and related-genes expression under stress (Siddiqui et al., 2020 and Wei et al., 2020). It is reported that, NO could participate in the plant mechanism towards abiotic stress like heat stress and other abiotic stresses. This NO can abate the deleterious effects of different stresses through the biosynthesis activation of thiol (R-SH) compounds like glutathione and phytochelatin (Siddiqui et al., 2020). It is reported by many researchers that nitric oxide could ameliorate the harmful effects of many stresses on tomato seedlings such as salt stress through increasing these enzymatic antioxidants (peroxidase, catalase, glutathione reductase, superoxide dismutase and ascorbate peroxidase) and photosynthetic pigment as well as decreasing the content of malondialdehyde and reactive oxygen species (Siddiqui et al., 2017). Under cadmium stress, applied NO could promote the tomato growth by modulating the metabolism of osmolytes, ascorbate-glutathione cycle enzymes and antioxidants (Ahmad et al., 2018). The ameliorative role of nitric oxide has been reported also under nutrient stress like copper stress (Dong et al., 2013 and Wang et al., 2015), sulfur stress (Siddiqui et al., 2020), boron (Kaya and Ashraf, 2015) and heavy metals (Wei et al., 2020).

Melatonin (N-acetyl-5-methoxytryptamine) is considered a plant hormone, which was isolated from the pineal gland of bovines in 1958 and plants in 1995 (Agathokleous et al., 2019). Several researchers have been reported about melatonin as a "pleiotropic signaling molecule", which could be produced in plants and animals as a hormone under stress (e.g., Mukherjee, 2018; Arnao and Hernández-Ruiz, 2019 and Jahan et al., 2020a). This plant hormone called "plant master regulator" due to its multiple biological roles as well as defensive roles under changing environmental conditions (Arnao and Hernández-Ruiz, 2019). These stressful conditions on plants include drought (Dai et al., 2020), salinity (Zahedi et al., 2020), heavy metals like chromium (Seleiman et al., 2020), heat stress (Jahan et al., 2020a) and oxidative stress (Jahan et al., 2020b). Under heat stress, melatonin could increase the tolerance of tomato seedlings towards heat stress through inducing the cycle of ascorbate-glutathione, improving the defense mechanism of their antioxidants and re-program the metabolic of polyamine and nitric oxide biosynthesis pathways (Jahan et al., 2020a). Melatonin also could mitigate the oxidative stress, which may be induced by heat stress of tomato seedlings through scavenging of excess reactive oxygen species and increasing the stability of the cellular membranes (Jahan et al., 2020a).

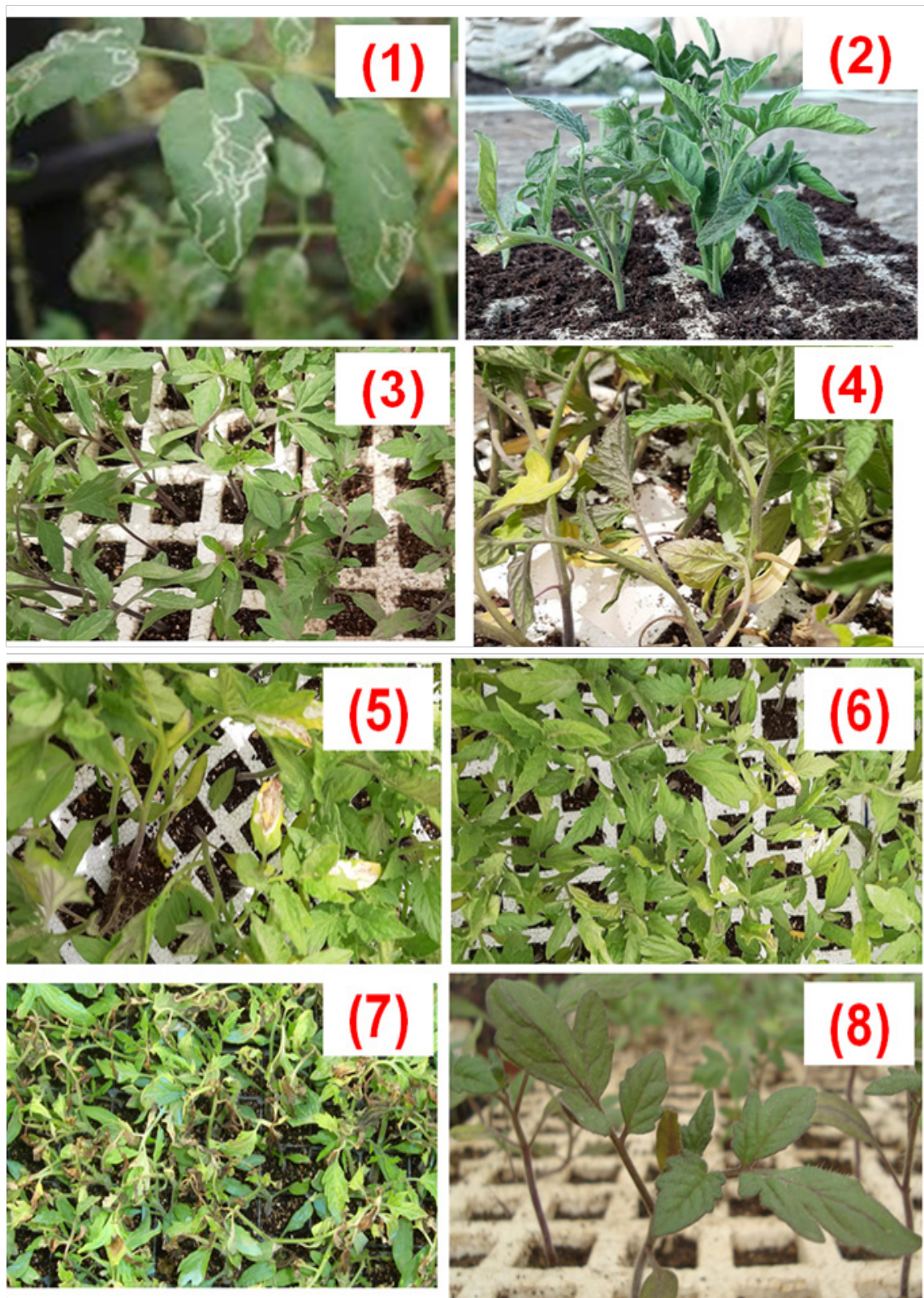


Fig. 1. There are many distinguished stresses have been reported for tomato seedlings grown under greenhouse in arid and semi-arid zones like in Egypt: leaf miners (photo 1), irrigation with saline water (photo 2), low temperature stress (photo 3), late blight (photo 4), *Tuta absoluta* (photo 5), N-deficiency (photo 6), early blight (photo 7) and P-deficiency stress (photo 8) (All photos by authors)

TABLE 1. Response of tomato seedlings to nutrient stress, the growth conditions, anti-stress used and its recommended dose.

Cultivar (cv.) or variety name	Growth conditions	Nutrient stress	Anti-stress	Used dose of anti-stress	Reference
cv: Five Star	Sand and perlite (1:1 ratio) pots, growth chamber	Sulfur deficiency (SO_4 : 71 mg l ⁻¹)	Nitric oxide (NO)	NO at 100 μM SNP	Siddiqui et al. (2020)
-----	Hydroponic culture,	Palladium stress (0.2, 0.5, 1.0 mM of PdCl ₂)	Palladium (Pd)	Pd at 0.2 mM PdCl ₂	Zhao et al. (2020)
cv: Ailsa Craig	Growth chamber	NH ₄ ⁺ toxicity (10 mM)	Abscisic acid (ABA)	ABA at 0.1 μM	González-Hernández et al. (2020)
Variety:Zhongshu 4	Greenhouse, pots filled with soil (pH: 7.91)	Toxicity of Cu & Cd (500 and 8 mg kg ⁻¹ , resp.)	Poly-aspartic acid (PASP)	PASP at 700 mg l ⁻¹	Hu et al. (2019)
cv. Five Star	Sand and perlite (2:1 ratio) pots, growth chamber	Toxicity of lanthanum (1.5 mM La)	Melatonin (Mel) and sulfur (S)	Mel (150 μM), S (1.0 mM SO_4^{2-})	Siddiqui et al. (2019)
-----	Peat moss in trays	Toxicity of Se & Ce (20 and 100 μM)	Selenium (Se) and cerium (Ce)	5 and 50 μM for Se and Ce, respectively	Saldaña-Sánchez et al. (2019)
-----	Pots filled with hydroponic solution	Toxic selenite & selenate (> 0.1 &> 1 mg Se l ⁻¹)	Se in selenite & selenate	0.05 mg l ⁻¹ for both selenite & selenate	Wang et al. (2019)
cv. M82 and cv. MicroTom	1/2 MS medium	Phosphate starvation (10 μM Pi)	Gibberellins (GA ₃)	10 μM GA ₃	Zhang et al. (2019)
-----	Pots filled with sand, perlite and peat (1:1:1)	Cadmium toxicity: 150 μM	Nitric oxide (NO)	NO (100 μM)	Ahmad et al. (2018)
cv. K-21	Pots filled with sand and perlite (1:3 ratio)	Cadmium (Cd) toxicity: 150 mg l ⁻¹	Selenium as selenite	Se (10 μM Na ₂ SeO ₃ · ρ H ₂ O)	Alyemeni et al. (2018)
cv. Lakshmi	Growth chamber	Cadmium toxicity (9 mg Cd kg ⁻¹)	Kinetin (KN)	KN: 10 μM	Singh et al. (2018)

Note: SNP (Na₂ [Fe (CN)₅NO]·2H₂O, which was used as an NO donor)

Brassinosteroids (BRs) are a plant hormone, which support cultivated plants in the growth, development and stress tolerance (Tong and Chu, 2018 and Pandey et al., 2020). Brassinosteroid is “poly-hydroxylated steroid phyto-hormone” having unique key roles during the early development of seedlings, flowering stage, vascular development and development of roots (Lee et al. 2018; Ahanger et al. 2020; Setsungnern et al. 2020). The tolerance of plants towards stress may depend on the interaction between BRs and other phytohormones including auxin, cytokinins, salicylic acid, and ethylene (Ahanger et al., 2020). It is reported about the promising role of

applied BRs in protecting the environment under stress (Soares et al., 2020). Exogenous applied and endogenous BRs was found to increase the tolerance of tomato plants against different stresses such as salinity (Ahanger et al. 2020), drought (Jangid and Dwivedi, 2017, Lee et al., 2018 and Nie et al., 2019), low temperature stress (Khan et al., 2019) and for other stressed plants like heat stress on *Arabidopsis* (Setsungnern et al., 2020), cadmium stress on pepper (Kaya et al., 2020), lead stress on *Brassica juncea* (Soares et al., 2020) and heat stress on barley (Sadura et al., 2020). Therefore, BRs are plant growth regulators that recognize the promoting the

division and stretching of plant cells, vascular differentiation and the resistance against stressful conditions (Soares et al., 2020).

Management and Production of Protected Tomato Seedlings under Heat Stress

The universe faces a lot of troubles including the population explosion, climate changes and global warming as well as the overexploitation of natural resources, which threaten the loss of global biodiversity (Souza and Prevedello, 2020). The changing in climate could threaten the crop production through the physical damage resulting from extreme climate events such as flooding and drought as well as the physiological changes induced by heat stress (Wan, 2015). Temperature is considered the most important environmental factor affecting the crop production, where each plant growth stage is totally controlled by temperature (Sakhonwasee and Phingkanan, 2017). Due to the extreme high temperatures particularly under arid zones, the cultivated plants in greenhouse will suffer from the heat stress in summer. The heat stress may support the over-production of reactive oxygen species (ROS), which damage the plant defense system and reduce its growth rates (Jahan et al., 2019).

The production of tomato seedlings under heat stress has gained the attention of many researchers as presented in Table 2. They found that tomato seedlings can mitigate the harmful effects of the heat stress by exogenous applied many anti-stress like applied calcium compounds (Sakhonwasee and Phingkanan, 2017), spermidine (Sang et al., 2016), ascorbic acid (Alayafi, 2019), nitrate compounds (Nafees et al. 2019), salicylic acid (Jahan et al., 2019), melatonin (Jahan et al., 2020b), sucrose and silicon (EL-Aidy et al., 2020). Several mechanisms could be used by tomato seedlings under heat stress like alleviating the oxidative stress of non- and enzymatic antioxidants by applied spermidine, increase proline content, the activity of photosynthesis by applied salicylic acid, enhancing the thermo-tolerance of tomato seedlings to heat stress by applied ascorbic acid, controlling over-accumulation of hydrogen peroxide and superoxide and lowering the lipid peroxidation content through application of melatonin.

Therefore, it could be concluded that, the production of tomato seedlings under greenhouse

conditions in arid and semi-arid zones in summer has a crucial problem represents in the heat stress. This production definitely requires more precautions and the effective management. This heat stress may cause over accumulations of ROS leading to mis-folds or dis-organized cellular homeostasis, deformed the structure of protein and impeded its synthesis as well as the disruption of the cell division and its growth due to the reduction in seedling water content (Jahan et al., 2019). The photosynthesis also will be damaged under heat stress through altering the photosynthetic components such as the thylakoid membranes, the photosystem II complex and the enzyme of ribulose 1,5-bisphosphate carboxylase (Sakhonwasee and Phingkanan, 2017).

Due to its potential for human nutrition, tomato cultivation under different environmental conditions is a crucial issue. So, the cultivation of tomato in open fields and under greenhouses is a common approach. The tomato cultivation under the greenhouse has become popular in different countries for the intensive production. This intensive production requires over-application of chemical fertilizers, which may cause greenhouse gas emissions including CH₄, CO₂, and N₂O contribute to global warming (Maham et al., 2020). This problem could be distinguished particularly in arid and semi-arid zones, which the greenhouse in summer may create a heat stress leading to soil salinization and damage for cultivated plants. These elevated temperatures in greenhouse may cause heat stress leading to generate oxidative stress and ROS, which severely damage the yield of tomato (Tonhati et al., 2020).

It is worth to mention that, the optimum temperature for tomato seedlings growth ranges from 18 to 30 °C, whereas the growing of seedling may decrease when it increases more than 35 °C (EL-Aidy et al. 2020). On the other hand, the optimum temperature during tomato plant flowering and fruit growth ranges from 18 to 25 °C (Tonhati et al., 2020). Therefore, the growth and production of tomato seedlings under greenhouse conditions may mainly depends on the growth stage, the stressful conditions and its duration, which control to what extent control the damage in cell metabolism functions. Again, the heat stress for tomato seedlings may include shortening the growth cycle, accelerating seedling senescence and leading to significant losses in tomato yield (Tonhati et al., 2020).

TABLE 2. Response of tomato seedlings to heat stress and its growth conditions.

Seedling age at heat stress treating	Growth conditions(cultivated cultivar)	Most important findings of the study	Reference
At the 3 rd true leaf, 38/28°C day/night for 7 days, spraying 1 mM spermidine	Growth chamber (cv. Puhong 968)	Spraying spermidine may alleviate the damage of heat stress through enhancing oxidative stress of non- and enzymatic antioxidants	Sang et al. (2016)
At the 3 rd week old of seedlings, 39/29°C for 14 days	Growth chamber (cv. Luktho)	Foliar application of the CaCl ₂ , CaNO ₃ , MgCl ₂ , or KNO ₃ solution mitigated heat stress effect by reducing the ROS	Sakhonwasee and Phingkanan (2017)
After transfer into hydroponics, 40 °C for 8 h/day for 7 days, applied 0.5 mM AsA	Plants were grown in peat moss for 35 days, then transferred into hydroponic system	Ascorbic acid (AsA) may be considered a key signaling molecule enhances the thermo-tolerance of tomato seedlings	Alayafi (2019)
Seedlings transferred into pots, grown for 25 days at 45/32°C (day/night)	Growth chamber, (NUN 5024 var.), seeds primed in Mg(NO ₃) ₂	Priming seeds in Mg(NO ₃) ₂ (from 5 to 10 mM) may improve germination in normal (25°C) and ameliorate high temperature stress (40°C)	Nafees et al. (2019)
At the 5 th true leaf, seedlings exposed to 42 °C for 36 h	Growth chamber (cv. Hezuo 903), at 28/19 °C (day/night), salicylic acid (1 mM) sprayed for 7 days	Salicylic acid may increase proline content, the activity of photosynthesis and antioxidant enzyme functions	Jahan et al. (2019)
At the 4 th true leaf, seedlings exposed to 42 °C for 24 h	Growth chamber (cv. Hezuo 903), at 28/19 °C (day/night), melatonin (100 µM) sprayed for 7 days	Melatonin may control over-accumulation of hydrogen peroxide and superoxide, then lowering the lipid peroxidation content	Jahan et al. (2020b)
At 18 th day-old seedlings, sprayed 3 times and sampling after 4 and 5 weeks	In greenhouse (super strain B variety), under heat stress 45/27°C (day/night) for 35 days	Foliar application of sucrose (10%), silicon (500 mg l ⁻¹) and plant probiotics (100 mg l ⁻¹) improved growth and quality of tomato seedlings	EL-Aidy et al. (2020)

Cultivated plants like other organisms are facing different abiotic and biotic stresses during their life and should adapt towards this stress. This adaptation is including the defense of these plants for their existence. This defense system has the ability to manage the plant genes in the regulation of all plant processes of growth and development. This regulation is considered stress management (Barozai and Aziz, 2018). The heatstress management could be achieved

via plant conventional breeding and plant engineering using the genetic approaches (Ye et al., 2019), as well as many agronomic practices (Fahad et al., 2017). These practices include exogenous application of osmo-protectants and growth regulators (Fahad et al. 2017), calcium compounds, spermidine, ascorbic acid, nitrate compounds, salicylic acid, melatonin, sucrose and silicon (as presented in Table 2) as well as nanoparticles (Ye et al., 2019).

Conclusion

The universe suffers from climate changes and global warming, which lead to increase the atmospheric temperature especially under the greenhouse conditions. Under arid conditions, the production of tomato seedlings under greenhouse system during the highest temperatures (mainly July and August) is a great challenge due to the heat stress inside and outside the greenhouse. So, this production should be managed through application of the proper amendments including the chemical (*e.g.*, Si, Se, Ca, Mg), organic (*e.g.*, sucrose, spermidine, ascorbic acid, melatonin and proline) and biological candidates (*e.g.*, plant probiotics). The heat stress may cause a serious threat for tomato seedlings production under such previous conditions, which generates a huge amount of ROS and oxidative stress. This stress also may reduce the photosynthetic activity in seedlings, the water content, metabolic processes and decline the growth rates and in turn the projected yield of tomato. Therefore, further studies are needed on the physiological, biochemical, anatomical and molecular levels in tomato seedlings under heat stress. The agronomic approaches and nanomaterials also are needed for more studies as management tools for heat stress.

Acknowledgement

The authors thank the staff members of Physiology and Breeding of Horticultural Crops Laboratory, Dept. of Horticulture, Fac. of Agric., Kafrelsheikh University, Kafr El-Sheikh, Egypt for supporting this work.

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