Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 13(1), 89-101, 2023
Journal of the Institute of Science and Technology, 13(1), 89-101, 2023

ISSN: 2146-0574, eISSN: 2536-4618

Biology **DOI: 10.21597/jist.1179027**

Research Article

Received: 22.09.2022 **Accepted: 06.12.2022**

To Cite*:* Baltacıer, G., Donat S. & Acar, O. (2023). The Effects of Exogenous Salicylic Acid and Strigolactone Applications on Seedling Growth and Antioxidant Activity in Tomato Seedlings Under Short-Term Drought Stress. *Journal of the Institute of Science and Technology*, 13(1), 89-101.

The Effects of Exogenous Salicylic Acid and Strigolactone Applications on Seedling Growth and Antioxidant Activity in Tomato Seedlings Under Short-Term Drought Stress

Gamze BALTACIER[1], Sevgi DONAT[1], Okan ACAR[2*]

Highlights:

- Limited information is available on exposure of ready-made seedlings to drought stress, such as the commercial tomato variety "Full F1"
- The antioxidant capacity of the seedlings improved when SA (0.1 mM) and GR24 (0.015 mM) were applied together in commercial tomato seedlings under drought stress
- SA and GR24 applications alone were found to be less effective than their combined application

Keywords:

- Oxidative stress
- Drought stress
- GR24
- Salicylic acid
- *Solanum lycopersicum* L.

ABSTRACT:

Drought is the main abiotic stress factor that negatively affects the growth, development, and yield of plants. Salicylic acid (SA) is a plant growth regulator associated with stress tolerance in plants. Exogenous application of SA prevents against stress dependent damage. Strigolactones (SLs) are another phytohormone in plants, they are known to positively affect plant growth with exogenous applications due to their potential to stimulate the tolerance system of plants under stress conditions. The aim of this study is determine to SA and GR24 effects on the negative impacts of drought stress on tomato "Full F1" seedlings, which is the most preferred commercial variety by professional farmers in Çanakkale (Turkey), based on physiological [(shoot-root length, biomass, relative water content (RWC), specific leaf area (SLA), total chlorophyll content (SPAD)] and biochemical parameters [Total protein amount, glutathione reductase activity (GR), catalase activity (CAT), peroxidase activity (POX), ascorbate peroxidase activity (APX), hydrogen peroxide amount (H_2O_2), lipid peroxidation amount (TBARS)]. Fourty-five days old seedlings kept five days for acclimation, then the seedlings were treated with exogenous GR24 (0.015 mM) and SA (0.1 mM) applications. According to our results, Full F1 tomato variety was adversely affected by short-term drought stress. However, especially SA+GR24 application reduced lipid peroxidation by regulating antioxidant capacity and increased drought tolerance of this cultivar. In this context, it can be said that the combined use of these phytohormones can be used to protect the Full F1 tomato variety from drought stress damage.

[1] Gamze BALTACIER (**Orcid ID**: 0000-0001-9299-3115), Sevgi DONAT (**Orcid ID**: 0000-0001-6482-7507), Çanakkale Onsekiz Mart University, School of Graduate Studies, Biology Department, Çanakkale, Türkiye

[2] Okan ACAR (**Orcid ID**: 0000-0002-9818-8827), Çanakkale Onsekiz Mart University, Faculty of Science, Biology Department, Çanakkale, Türkiye
Corresponding Author*: *Okan ACAR, e-mail: oacar@comu.edu.tr*

This study was presented as an oral presentation at two different congresses. The data on the physiological parameters of the article were presented in the "III. International Agricultural, Biological, Life Science Conference, AGBIOL 2021" congress and data on biochemical parameters were presented as an oral presentation (summary paper) at the "3rd International Symposium on Biodiversity Research, ISBR 2021" congress held in Erzurum on 20-22 October 2021.

INTRODUCTION

Disruption of the optimum conditions where temperature, light and humidity are combined, in which plants grow best, results in stress for plants. In fact, plants are exposed to abiotic (drought, salinity, high and low temperature etc.) and biotic stress factors (pathogens, insects, herbivores, etc.) in natural living conditions (Matysiak et al., 2020). However, today it is accepted that global climate change has increased and spread the severity of environmental stress factors. While the uncontrolled use of natural resources and the increase in global climate temperatures are especially effective in the aggravation of drought, they have become a major threat to sustainable crop production (Hasanuzzaman et al., 2020). Since drought negatively affects the growth and development processes of plants, there are many current studies on the harmful effects of drought stress on plants (Sattar et al., 2021; Sedaghat et al., 2021). Drought stress causes disruption in plant cell proliferation and expansion, leaf size, shoot elongation, root proliferation, and crop growth and biomass accumulation (Chakma et al., 2021). Plants have developed special adaptation mechanisms to avoid the damage caused by abiotic stresses or to tolerate the negative effects of stress. Accordingly, plants can reduce leaf size and number, increase the area and length of roots, create thicker cuticle and wax layers, change stomatal opening and closing rates, induce cell turgor mechanisms, and reduce light absorption by reflecting light (Çelik et al., 2017). These adaptation mechanisms are not sufficient to protect the plant when the plant is exposed to long-term stress, and in this case, more advanced molecular mechanisms come into play. Drought stress or other environmental stresses cause oxidative stress by increasing the concentrations of reactive oxygen species (ROS) such as hydroxyl radical ($^{\cdot}OH$), hydrogen peroxide (H_2O_2), singlet oxygen ($_1O^2$), superoxide radical ($O_2^{\cdot -}$) in plant cells. Under oxidative stress conditions, ROS attack proteins, lipids, carbohydrates, pigments, nucleic acids and damage their structures (Gill and Tuteja, 2010). To cope with stress, plants generally use enzymatic (superoxide dismutase (SOD), ascorbate peroxidase (APX), peroxidase (POX) and catalase (CAT)) or non-enzymatic (carotenoids, ascorbate, glutathione, tocopherols) antioxidant defense systems (Hasanuzzaman et al., 2020; Sedaghat et al., 2021). In fact, enzymatic antioxidants convert H_2O_2 released as a result of photorespiration in peroxisomes, cytosol and mitochondria into harmless H_2O_2 for the cell (Hasanuzzaman et al., 2020).

Phytohormones are signal molecules known as plant growth regulators and synthesized by plants at low concentrations (Jogawat et al., 2021). These hormones, which have important roles in regulating plant growth and development, significantly determine the responses to biotic and abiotic stresses (Rhaman et al., 2020). Auxins (IAAs), cytokinins (CKs), gibberellins (GAs), abscisic acid (ABA), ethylene (ET), brassinosteroids (BRs), salicylic acid (SA), and strigolactone (SL)) are well-known phytohormones in plant growth and development (Faizan et al., 2020; Rhaman et al., 2020).

Strigolactones (SLs) are known as terpenoid lactones derived from naturally occurring carotenoids in various plants. Playing a key role in regulating plant growth and development under stressful conditions, SLs were first discovered in root exudates for their ability to stimulate the germination of seeds of the root parasitic plant Striga (Xie et al., 2010; Mubarik et al., 2021). Studies have shown that SLs also play a role in responses to most abiotic stresses, particularly drought. In Arabidopsis, SL induced stomatal closure by playing a positive role in the regulation of drought and salinity stress responses (Van Ha et al., 2014). Exogenous SL application improved water relations and increased antioxidant enzyme activities in corn seedlings to provide tolerance to drought stress (Sattar et al., 2021). In another study, the application of synthetic strigolactone (GR24) to tomato seedlings under salt stress increased the photosynthetic pigment content and improved the activities of antioxidant enzymes (SOD, POX, CAT, APX and GR) (Liu et al., 2022).

Salicylic acid (SA), a phytohormone with a phenolic structure, is a potent signaling molecule involved in intracellular communication pathways by regulating physiological and biochemical functions such as photosynthesis, stomatal responses, and responses to biotic and abiotic stresses in plants (Jayakannan et al., 2015; Wani et al., 2017). The effects of exogenous SA depend on plant species, growing conditions, severity and duration of stress (Wani et al., 2017; Yanik et al., 2018). In a study, exogenous SA application to wheat plant under drought stress increased the total amount of chlorophyll (Noreen et al., 2017). Exogenous SA application improved the cell damage caused by H_2O_2 by increasing the net photosynthesis rate, water use efficiency and antioxidant enzyme activities in drought-stressed tomato plants (Lobato et al., 2021). Drought tolerance of wheat effectively improved via SA and SL by stimulating ROS scavenging enzymes (Sedaghat et al., 2017).

Tomato (*Solanum lycopersicum* L.) is one of the most important agricultural crops worldwide due to its industrial products and nutrient content (Liu et al., 2022). Turkey ranks third in tomato production after China and India (FAO, 2020). Tomatoes, which were produced 13.2 million tons in 2020, took the first place in vegetable agriculture, accounting for 42% of vegetable production alone (IAEPD, 2021). In addition, according to Crop Production Statistics, 13.09 million tons of tomato production was realized in Turkey in 2021. The most important producing regions in tomato production in Turkey are Mediterranean, Aegean and Marmara, respectively. Tomato production in Çanakkale was 580 thousand tons in 2021 (TSI, 2021). Tomato is a sensitive plant to abiotic stress factors. It is known that temperature and drought have the most limiting effects. Especially drought stress significantly reduces the yield and product quality in the vegetative and early reproductive stages of the tomato life cycle (Çelik et al., 2017; Liu et al., 2022).

The aim of this study is to investigate the effects of SA and a synthetic SL (GR24), on physiological and biochemical parameters on the negative effects of short-term drought stress on Full F1 seedlings, which is the most preferred table tomato variety by farmers in Çanakkale.

MATERIALS AND METHODS

Plant Material and Growing Conditions

Tomato (*Solanum lycopersicum* L.) belongs to the *Solanaceae* family. In this study, 45-day-old ready-to-plant seedlings of the Full F1 variety were used (Figure 1). Seedlings ready for planting were grown in pots in a plant growth cabinet under in vitro conditions, at 22-24°C and 16/8 (light/dark) photoperiod. The grown plants were irrigated with Hoagland nutrient solution (100%) (Hoagland and Arnon, 1950). The seedlings were obtained from a local company in Çanakkale (Turkey) that sells pesticides and vegetable seedlings.

Figure 1: Exogenous GR24 (Synthetic Strigolactone and SA (Salicylic Acid) (application to of 45-d-old *Solanum lycopersicum L*. Full F1 seedlings

Drought Stress, Salicylic Acid and Strigolactone Applications

After 5 days of acclimatization, the seedlings were divided into 2 groups: control group [Control (C), Salicylic Acid (SA), Synthetic Strigolactone (GR24) and Salicylic Acid + Synthetic Strigolactone (SA+GR24)] and drought group [Drought (D), Salicylic Acid (D+SA), Synthetic Strigolactone

(D+GR24) and Salicylic Acid + Synthetic Strigolactone (D+SA+GR24)]. When the seedlings were 50 days old, 0.015 mM GR24 (purchase from Binne Zwanenburg) (dissolved in acetone) (Lu et al., 2019) and 0.1 mM SA (Lobato et al., 2021) were applied exogenously to the plants (with Tween 20: it is a surfactant. It allows the applied solution to stick on the leaf. MERCK, Cat No:8.22184.0500). In the drought group seedlings, 7-day irrigation was stopped, and water scarcity was achieved. The leaves of the seedlings were sampled after one week of drought stress. Tissue samples for analysis were stored in a deep freezer at -20°C.

Physiological Parameters

Root and shoot lengths of the plants were measured and recorded with the help of a ruler. Biomass the weight of 6 seedlings from each group was weighed on sensitive scales and the average was taken, and the seedling weights of the plants were determined. The total amount of chlorophyll was measured with a Minolta brand chlorophyll meter (model SPAD-502) and the total amount of chlorophyll was calculated according to Peryea and Kammereck (1997). The mature leaf parts of the plants were used for the determination of the relative water content (RWC). The RWC of the plants was determined according to Smart and Bingham (1974) using Equation (2.1). Leaf areas were calculated using ImageJ program (image processing program) by photographing selected leaves, and specific leaf area (SLA) was determined using Equation (2.2) (Wilson et al., 1999).

$$\%RWC = \frac{FW-DW}{TW-DW} X\ 100 \tag{1}$$

(FW: Wet weight, TW: Turgor weight, DA: Dry weight)

$$SLA = \frac{Area\ (cm^2)}{Dry\ weight\ (mg^{-1})} \tag{2}$$

Biochemical Parameters

Total protein amounts were determined according to Bradford (1976), spectrophotometric CAT enzyme activity according to Bergmeyer (1970), POX activity according to Kanner and Kinsella (1983), GR activity according to Foyer and Halliwell (1976), APX activity according to Nakano and Asada (1981) was determined. TBARS amounts were determined according to Madhava and Sresty (2000), and H_2O_2 amounts were determined according to Cheeseman (2006).

Statistical Analysis

The data were made with Tukey test using one-way analysis of variance (ANOVA). SPSS (Statistical Package for the Social Sciences, version 21) program was used for statistical analysis. Significance levels were shown in graphs. Those comparisons with $p \leq 0.05$ were taken as significantly different.

RESULTS AND DISCUSSION

Root and Shoot Length

In the control group, shoot length decreased by 8%, 6% and 3%, respectively, with SA, GR24 and SA+GR24 applications compared to the control. While root length decreased by 12% with SA application, it did not change with GR24. However, SA+GR24 application increased root length by 18% (Figure 2A). Shoot length in seedlings under drought stress decreased 1-3% with SA, GR24 and SA+GR24 applications. Root length increased by 26%, 8% and 20% in all treatment groups compared to the control, respectively (Figure 2B). Accordingly, it was determined that the application of SA+GR24 caused an increase in root length in response to drought stress of tomato seedlings.

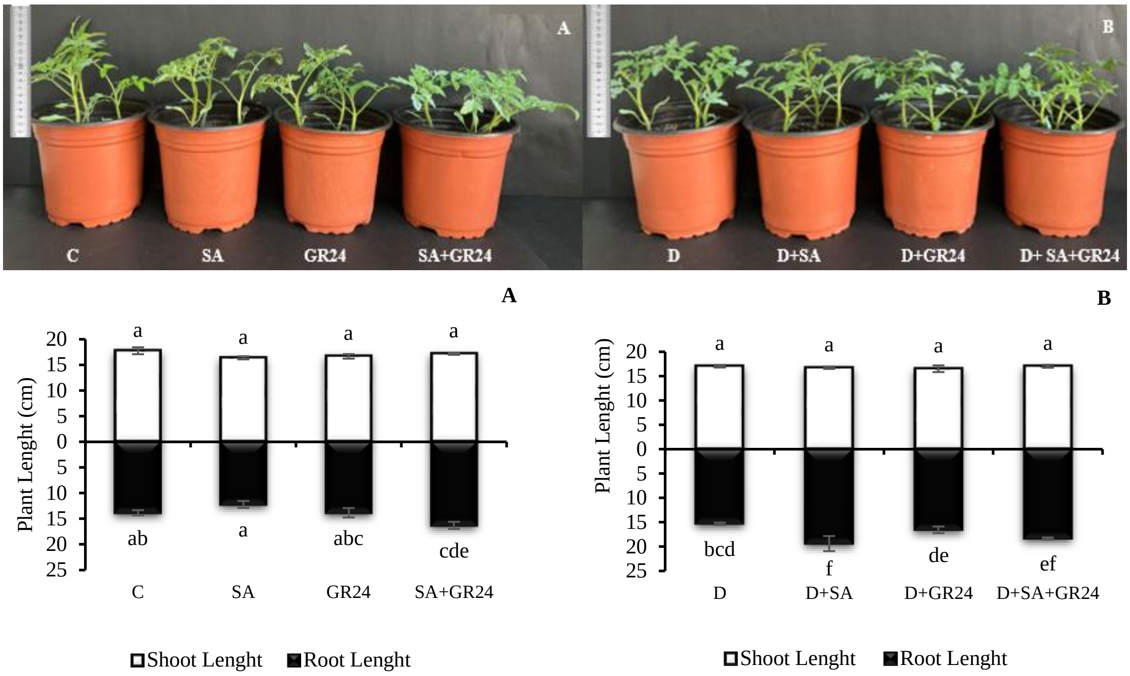

Figure 2: The effects of SA and GR24 treatments on root and shoot length in tomato (cv. Full F1) seedlings [A; Control group (C: Control, SA: Salicylic acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic acid and Synthetic strigolactone), B; Drought group (D: Drought, D+SA: Drought and Salicylic acid, D+GR24: Drought and Synthetic strigolactone, D+SA+GR24: Drought and Salicylic acid+Synthetic strigolactone)] (Means values followed by different letters are significantly different at *p* <0.05)

Biomass

The seedling weight decreased by 6% with SA application in the control group compared to the control and decreased by 3% and 12% with SA and GR24 applications in the drought group, respectively. However, these reductions were not statistically significant (p<0.05) (Figure 3).

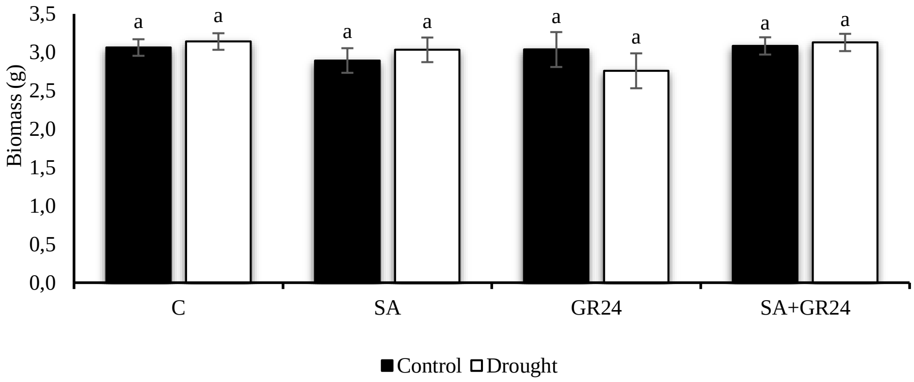

Figure 3: The effects of SA and GR24 treatments on biomass in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid+Synthetic strigolactone) (Means values followed by different letters are significantly different at *p* <0.05)

Total Chlorophyll Content (SPAD)

In the control group, the total amount of chlorophyll decreased by 15%, 10% and 13% compared to the control group with all applications. Conversely, in the drought group, all treatments increased the total chlorophyll content by 1-10% (Figure 4). Accordingly, hormone applications were effective in preventing chlorosis due to drought stress.

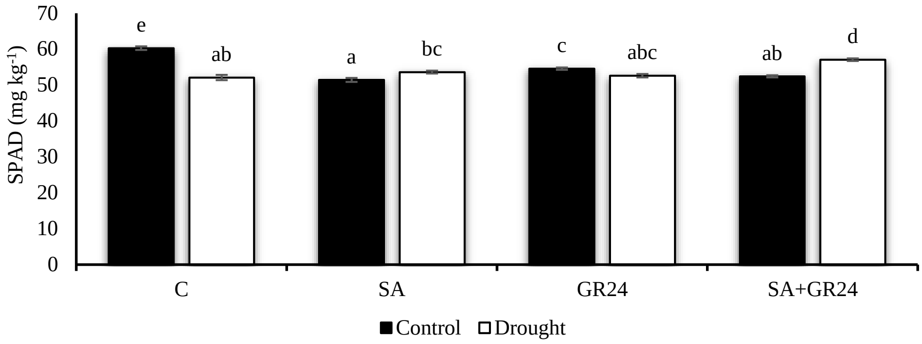

Figure 4: The effects of SA and GR24 treatments on total chlorophyll content in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid+Synthetic strigolactone) (Means values followed by different letters are significantly different at $p < 0.05$)

Relative Water Content (RWC)

In the control group, RWC increased by 2-5% with all treatments. In the drought group, RWC increased by 14%, 9% and 19%, respectively, compared to the control (Figure 5). These results indicate that the combined SA and GR24 application is effective in maintaining the water content of seedlings.

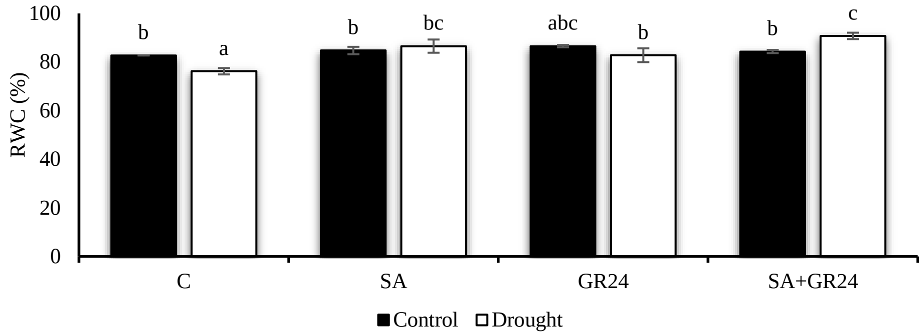

Figure 5: The effects of SA and GR24 treatments on RWC in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid+Synthetic strigolactone) (Means values followed by different letters are significantly different at $p < 0.05$)

Specific Leaf Area (SLA)

It was determined of SLA, which increased by 9% with GR24 application in the control group, increased 1.2 times with SA+GR24 application. In the drought group, with SA, GR24 and SA+GR24 applications, SLA increased by 20%, 1.2 and 1.3 times, respectively, compared to the control. Our results show that SA and GR24 applications increase SLA more effectively (Figure 6).

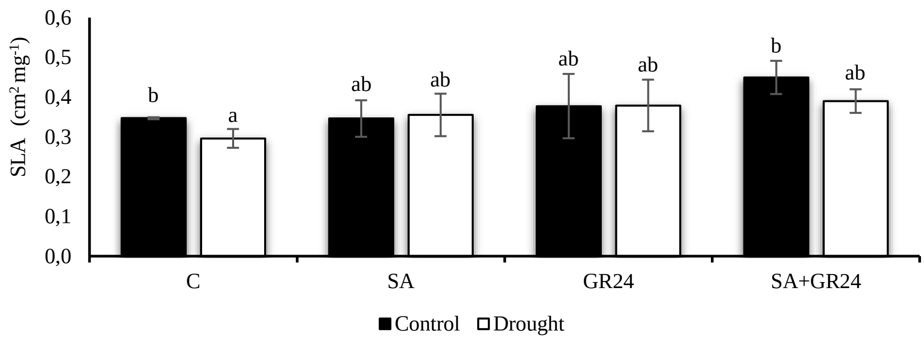

Figure 6: The effects of SA and GR24 treatments on SLA in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid + Synthetic strigolactone) (Means values followed by different letters are significantly different at $p < 0.05$)

Hydrogen Peroxide (H_2O_2) Amount

It was determined that the amount of H_2O_2 increased by 11%, 1.4 times and 1.3 times, respectively, in the SA, GR24 and SA+GR24 application groups in the control group compared to the control group. In the drought group, the amount of H_2O_2 decreased by 37%, 32% and 35%, respectively, in all treatment groups. According to our results, the amount of H_2O_2 that increased with drought stress decreased effectively with SA and GR24 applications (Figure 7).

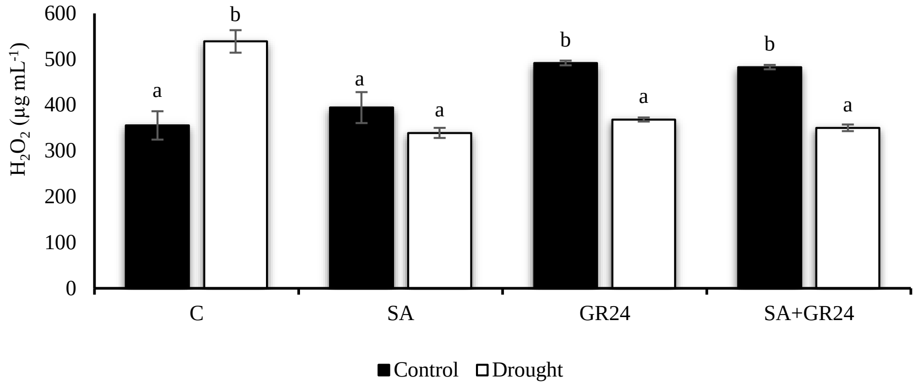

Figure 7: The effects of SA and GR24 treatments on H_2O_2 amount in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid+Synthetic strigolactone) (Means values followed by different letters are significantly different at $p<0.05$)

Lipid Peroxidation Amount (TBARS)

The amount of lipid peroxidation increased by 4-6% in the control group compared to the control group with all treatments. In the drought group, SA decreased by 42%, 35% and 52% in the GR24 and SA+GR24 groups, respectively. Accordingly, all treatments drastically reduced the increased amount of lipid peroxidation in the control group (Figure 8).

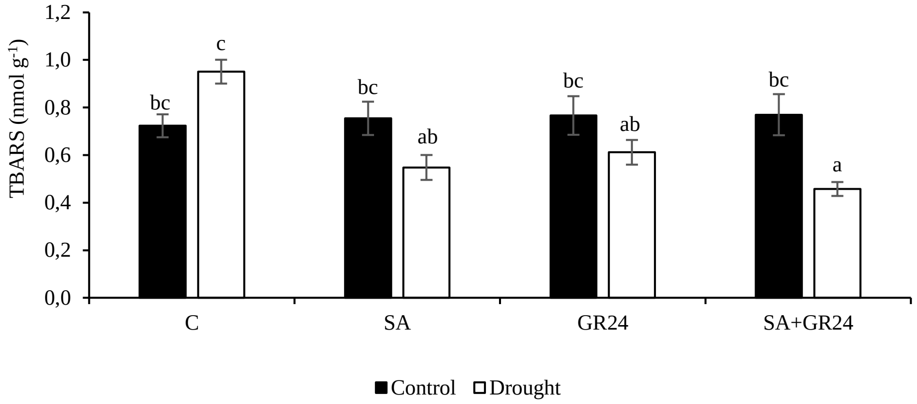

Figure 8: The effects of SA and GR24 treatments on TBARS amount in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid+Synthetic strigolactone) (Means values followed by different letters are significantly different at $p<0.05$)

Total Protein Amount

In the drought group, all treatments increased the total protein amount. Accordingly, an increase of 1.6 times was determined with the application of SA and 1.7 times with the application of SA+GR24. Similarly, total protein content in the drought group increased 2.4-times, 1.7-times and 1.4-times, respectively, with all treatments compared to the control (Figure 9). Our results show that SA and GR24 hormone treatments effectively increase the protein content of tomato seedlings under drought stress.

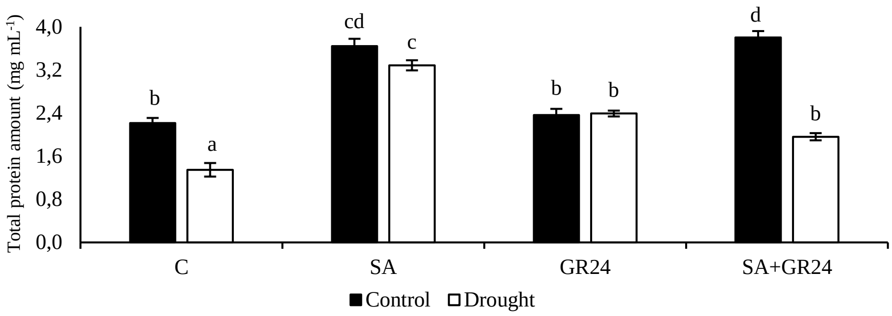

Figure 9: The effects of SA and GR24 treatments on total protein amount in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid + Synthetic strigolactone) (Means values followed by different letters are significantly different at $p<0.05$)

Glutathione Reductase Activity (GR)

In the control group, GR activity increased 2.2 times, 2.5 times and 1.7 times, respectively, with all treatments compared to the control. In the drought group, SA and GR24 applications decreased GR activity by 50% and 43%, respectively, while it increased 1.6 times with SA+GR24 application. (Figure 10).

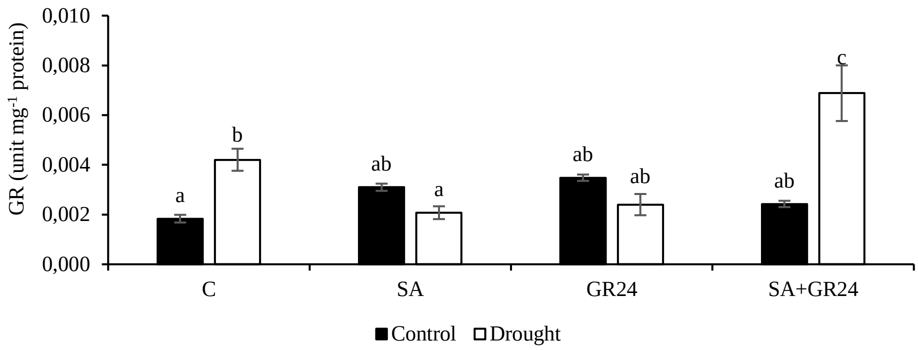

Figure 10: The effects of SA and GR24 treatments on GR activity in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid+Synthetic strigolactone) (Means values followed by different letters are significantly different at $p<0.05$)

Ascorbate Peroxidase Activity (APX)

In the control group, all treatments reduced APX activities. These decreases were determined as 55% with the application of SA and 50% with the application of SA+GR24. Compared to the control, there was a decrease of 57%, 37% and 49% in all treatment groups, respectively, in the drought group (Figure 11). Our results indicate that APX activity is more effective with GR24.

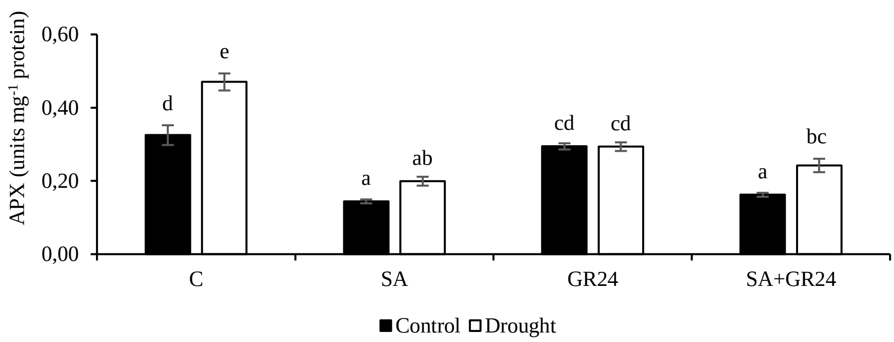

Figure 11: The effects of SA and GR24 treatments on APX activity in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid+Synthetic strigolactone) (Means values followed by different letters are significantly different at $p<0.05$)

Peroxidase Activity (POX)

In the control group, POX activity increased by 28% compared to the control with GR24 alone. However, POX activity in seedlings under drought stress increased only with the application of SA+GR24 (Figure 12). According to this, It has been determined that the application of both hormones together is more effective in cleaning the H_2O_2 that increases with drought stress.

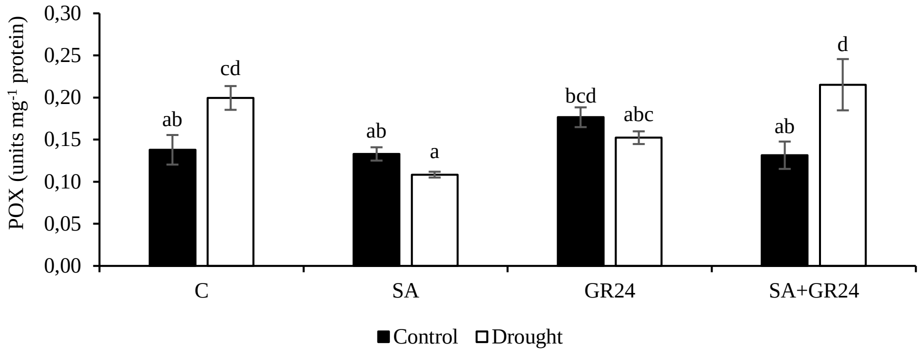

Figure 12: The effects of SA and GR24 treatments on POX activity in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid + Synthetic strigolactone) (Means values followed by different letters are significantly different at *p*<0.05)

Catalase Activity (CAT)

It was determined that the CAT activity was decreased by 60%, 42% and 51% in the control group compared to the control in all treatment groups, respectively. In the drought group, CAT activity, which decreased by 39% with SA application, increased 1.9 times with GR24 application (Figure 13). According to our results, hormone applications did not cause a significant change in CAT activities in the control group. Conversely, GR24 treatments were found to effectively increase CAT activity in seedlings under drought stress.

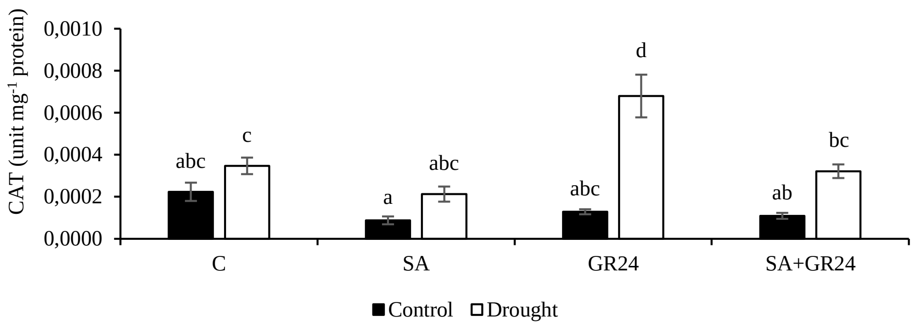

Figure 13: The effects of SA and GR24 treatments on CAT activity in tomato (cv. Full F1) seedlings (C: Control, SA: Salicylic Acid, GR24: Synthetic strigolactone, SA+GR24: Salicylic Acid+Synthetic strigolactone) (Means values followed by different letters are significantly different at *p*<0.05)

Water scarcity is a factor that limits growth and yield for tomatoes as well as for most cultural plants. Understanding the drought effects of existing varieties due to global climate change is important for farmers who will use these varieties. In this study, the effects of SA and SL (GR24) applications on physiological and biochemical parameters of 45-day-old “Full F1” commercial tomato seedlings under short-term drought stress were investigated.

It has been reported that the exogenous SA application in tomatoes improves negative effects on biomass (Lobato et al., 2021). In contrast, our results have shown that there is no significant change in Full F1 tomato variety with drought stress on biomass. This suggests that longer drought period may have a negative effect on the biomass of Full F1 variety. On the other hand, short-term drought stress did not affect the shoot length of seedlings, but significantly reduced root lengths in both the control and drought group. Moreover, the SA+GR24 application significantly increased the root length compared to the control in both groups. Our results have shown that the SA+GR24 application significantly increased SLA in both groups compared to the control. Similarly, it has been reported that SA application in tomatoes under salt stress increases SLA, biomass, root and shoot length (Miomuni et al., 2016). Relative water content is used as a measure of water condition in plants, and it is known that RWC decreases in tomatoes with drought (Çelik et al., 2017). Accordingly, in our research, it was determined that the RWC of tomato seedlings with drought was significantly decreased and SA and GR24 applications help to protect the RWC of seedlings.

Chlorosis caused by drought causes negative effects of photosynthesis in most cultural plants and reduced yield. It is known that the amount of chlorophyll in tomatoes decreases with drought (Çelik et al., 2017; Nguy et al., 2021). According to our results, the amount of chlorophyll decreased by drought. However, SA and SL applications have prevented drought chlorosis in Full F1 variety, and even the SA+GR24 application increased significantly compared to the control group. Similarly, exogenous SA applications have been shown to have increased in corn (Sattar et al., 2021) and wheat (Noreen et al., 2017; Matysiak et al., 2020) under drought stress and increased tomatoes under heat stress (Jahan et al. 2019). In addition, exogenous GR24 applications are known to increase the chlorophyll content in corn under the stress of drought in tomatoes under salt stress (Sattar et al., 2021).

Oxidative stress refers to the presence of high concentration of oxy-radicals produced in the cell. Depending on oxidative stress, damage occurs at the level of cells, tissues, and organs in plants. Hydrogen peroxide is produced during detoxification of superoxide radical. Our results have shown that the amount of H_2O_2 increased significantly with drought compared to control in Full F1 variety, while all SA and GR24 applications are reduced. In addition, lipid peroxidation, which is an important criterion for the determination of oxidative stress caused damage, increased significantly with drought, while dramatic decreased especially with the SA+GR24 application. In this, it was determined that the significantly increased GR, POX, and CAT activities, one of the antioxidant defense system enzymes, is significantly increased compared to the control of the SA+GR24 application. Interestingly, the GR24 application stunned CAT activity under drought. It may be necessary to investigate in detail whether this is only from photorespirational H_2O_2.

Our results regarding enzyme activities are compatible with the research conducted with industrial tomato varieties under drought stress (Çelik et al., 2017). It has been shown in grapes that the increase in antioxidant defense ability is linked to drought tolerance (Min et al., 2019). In a study conducted in tomatoes vaccinated in drought-resistant seedlings, it was determined that the increase in antioxidant enzymes under drought stress reduces drought-related phytotoxicity and oxidative damage (Zhang et al., 2019). On the other hand, it has been shown that GR24 applications in tomatoes increase the activities and chlorophyll amount of antioxidant enzymes and increase the tolerance of salt, hot and cold stresses (Chi et al., 2021; Liu et al., 2022). In addition, GR24 applications reported to increase antioxidant activities in corn (Sattar et al., 2021) under drought stress (Sattar et al., 2021) and wheat (Sedaghat et al., 2021). Similar to our results, it has been shown that lipid peroxidation with increased enzyme activities in suppressing the increased oxidative damage with the water scarcity of exogenous SA application in tomatoes has been effective (Mimouni et al., 2016; Lobato et al., 2021). However, the increases of H_2O_2 scavenger enzymes such as POX and CAT were reported in the suppression of exogenous SA applications in wheat (Sedaghat et al., 2021; Sattar et al., 2021).

Research indicates that physiologically reduces drought damage through increased activity of GR24 and SA and antioxidant enzymes, indicating that phytohormones regulate cellular signals under abiotic stress conditions such as drought in plant biological processes (Salvi et al., 2021; Yang et al., 2022). It has been shown that the silence of the SLZF57 gene, which is activated by exogenous ABA in tomatoes, reduces drought resistance in the context of some enzyme activities (SOD, POX) and lipid peroxidation results (Gao et al., 2022). Similarly, in tomato slnPR1 mutants, the relationship between drought tolerance of this gene with drought-related tolerance with down-regulation decreased antioxidant enzymes and increased lipid peroxidation (Li et al., 2019). However, it has been reported that SLs provide a molecular connection between Mir156, a micro-RNA, a micro-RNA protected by drought, so that the aba-bond effect of the SLs has been reported (Visentin et al., 2020).

CONCLUSION

Nowadays, due to climate change, it is necessary to develop drought-resistant tomato varieties and it is recommended to determine physiological and biochemical properties such as RWC, proline content, POX activity, ascorbic acid in addition to agricultural properties for breeding programs (Ilakiya et al., 2022). According to our results, the Full F1 tomato variety sold as a seedling for farmers was adversely affected by short-term drought. However, especially the SA+GR24 application regulated antioxidant capacity and reduced lipid peroxidation and increased the drought tolerance of this variety. In this context, it can be said that the co-use of these phytohormones can be used in the protection of Full F1 tomato variety from drought stress damage.

Conflict of Interest

The article authors declare that there is no conflict of interest between them.

Author's Contributions

The authors declare that they have contributed equally to the article.

REFERENCES

Bergmeyer, N. (1970). Methoden der Enzymatichen Analyses. *Akademia Verlag*, Berlin, 1:636-647.

Bradford, M. M. (1976). A Rapid and Sensitive Method for the Quantitation of Microgram Quantities of Protein Utilizing the Principle of Protein-Dye Binding. *Analytical Biochemistry*, 72(1-2):248-254.

Çelik, Ö., Ayan, A. & Atak, Ç. (2017). Enzymatic and Non-enzymatic Comparison of Two Different Industrial Tomato (*Solanum lycopersicum*) Varieties Against Drought Stress. *Botanical Studies*, 58(1), 1-13.

Chakma, R., Biswas, A., Saekong, P., Ullah, H. & Datta, A. (2021). Foliar Application and Seed Priming of Salicylic Acid Affect Growth, Fruit Yield, and Quality of Grape Tomato Under Drought Stress. *Scientia Horticulturae*, 280: 109904.

Cheeseman, J. M. (2006). Hydrogen Peroxide Concentrations in Leaves Under Natural Conditions. *Journal of Experimental Botany*, 57: 2435–44.

Chi, C., Xu, X., Wang, M., Zhang, H., Fang, P., Zhou, J. & Yu, J. (2021). Strigolactones Positively Regulate Abscisic Acid-Dependent Heat and Cold Tolerance in Tomato. *Horticulture Research*, 8.

Faizan, M., Faraz, A., Sami, F., Siddiqui, H., Yusuf, M., Gruszka, D. & Hayat, S. (2020). Role of Strigolactones: Signalling and Crosstalk with Other Phytohormones. *Open Life Sciences*, 15(1): 217-228.

FAO, 2020. Food and Agriculture Organization of the United Nations, https://www.fao.org/faostat/en/#data/QCL (Date of access: 19 April 2022).

Foyer, C. H. & Halliwell, B. (1976). Presence of Glutathione and Glutathione Reductase in Chloroplasts: A Proposed Role in Ascorbic Acid Metabolism. *Planta*, 133: 21-25.

Gao, Z., Bao, Y., Wang, Z., Sun, X., Zhao, T. & Xu, X. (2022). Gene Silencing of SLZF57 Reduces Drought Stress Tolerance in Tomato. *Plant Cell, Tissue and Organ Culture*, 1-8.

Gill, S. S. & Tuteja, N. (2010). Reactive Oxygen Species and Antioxidant Machinery in Abiotic Stress Tolerance in Crop Plants. *Plant Physiology and Biochemistry*, 48(12): 909-930.

Hasanuzzaman, M., Bhuyan, M. H. M., Zulfiqar, F., Raza, A., Mohsin, S. M., Mahmud, J. A. & Fotopoulos, V. (2020). Reactive Oxygen Species and Antioxidant Defense in Plants Under Abiotic Stress: Revisiting the Crucial Role of a Universal Defense Regulator. *Antioxidants*, 9(8): 681.

Hoagland, D. R. & Arnon, D. I. (1950). The Water-Culture Method for Growing Plants Without Soil. In Circular. *California Agricultural Experiment Station*, 347: 32.

Ilakiya, T., Premalakshmi, V., Arumugam, T. & Sivakumar, T. (2022). Variability Analysis in Tomato (*Solanum lycopersicum* L.) Crosses Under Drought Stress. *Journal of Applied and Natural Science*, 14(SI): 49-52.

Jahan, M. S., Wang, Y., Shu, S., Zhong, M., Chen, Z., Wu, J. & Guo, S. (2019). Exogenous Salicylic Acid Increases the Heat Tolerance in Tomato (*Solanum lycopersicum* L.) by Enhancing Photosynthesis Efficiency and Improving Antioxidant Defense System Through Scavenging of Reactive Oxygen Species. *Scientia Horticulturae*, 247: 421-429.

Jayakannan, M., Bose, J., Babourina, O., Rengel, Z. & Shabala, S. (2015). Salicylic Acid in Plant Salinity Stress Signalling and Tolerance. *Plant Growth Regulation*, 76(1): 25-40.

Jogawat, A., Yadav, B., Lakra, N., Singh, A. K. & Narayan, O. P. (2021). Crosstalk Between Phytohormones and Secondary Metabolites in the Drought Stress Tolerance of Crop Plants: A review. *Physiologia Plantarum*, 172(2): 1106-1132.

Kanner, J. & Kinsella, J. E. (1983). Lipid Deterioration: β-Carotene Destruction and Oxygen Evolution in a System Containing Lactoperoxidase, Hydrogen Peroxide and Halides. *Lipids*, 18(3): 198-203.

Li, R., Liu, C., Zhao, R., Wang, L., Chen, L., Yu, W. & Shen, L. (2019). CRISPR/Cas9-Mediated SlNPR1 Mutagenesis Reduces Tomato Plant Drought Tolerance. *Plant Biology*, 19(1): 1-13.

Liu, H., Li, C., Yan, M., Zhao, Z., Huang, P., Wei, L. & Liao, W. (2022). Strigolactone is Involved in Nitric Oxide-Enhanced the Salt Resistance in Tomato Seedlings. *Journal of Plant Research*, 135(2): 337-350.

Lobato, A. K. D. S., Barbosa, M. A. M., Alsahli, A. A., Lima, E. J. A. & Silva, B. R. S. D. (2021). Exogenous Salicylic Acid Alleviates the Negative Impacts on Production Components, Biomass and Gas Exchange in Tomato Plants under Water Deficit Improving Redox Status and Anatomical Responses. *Physiologia Plantarum*, 172(2): 869-884.

Lu, T., Yu, H., Li, Q., Chai, L. & Jiang, W. (2019). Improving Plant Growth and Alleviating Photosynthetic Inhibition and Oxidative Stress from Low-Light Stress with Exogenous GR24 in Tomato (*Solanum lycopersicum* L.) Seedlings. *Frontiers in Plant Science*, 10: 490.

Madhava, R. K. V. & Sresty, T. V. S. (2000). Antioxidative Parameters in the Seedlings of Pigeonpea (*Cajanus cajan* L. Millspaugh) in Response to Zn and Ni Stresses. *Plant Science*, 157: 113-128.

Matysiak, K., Siatkowski, I., Kierzek, R., Kowalska, J. & Krawczyk, R. (2020). Effect of Foliar Applied Acetylsalicilic Acid on Wheat (*Triticum aestivum* L.) under Field Conditions. *Agronomy*, 10(12): 1918.

Mimouni, H., Wasti, S., Manaa, A., Gharbi, E., Chalh, A., Vandoorne, B. & Ahmed, H. B. (2016). Does Salicylic Acid (SA) Improve Tolerance to Salt Stress in Plants? A Study of SA Effects on Tomato Plant Growth, Water Dynamics, Photosynthesis, and Biochemical Parameters. *Omics: A Journal of Integrative Biology*, 20(3): 180-190.

Min, Z., Li, R., Chen, L., Zhang, Y., Li, Z., Liu, M. & Fang, Y. (2019). Alleviation of Drought Stress in Grapevine by Foliar-Applied Strigolactones. *Plant Physiology and Biochemistry*, 135: 99-110.

Mubarik, M. S., Khan, S. H., Sajjad, M., Raza, A., Hafeez, M. B., Yasmeen, T. & Arif, M. S. (2021). A Manipulative Interplay Between Positive and Negative Regulators of Phytohormones: A Way Forward for Improving Drought Tolerance in Plants. *Physiologia Plantarum*, 172(2): 1269-1290.

Nakano, Y. & Asada, K. (1981). Hydrogen Peroxide is Scavenged by Ascorbate-Specific Peroxidase in Spinach Chloroplasts Plant. *Cell Physiology*, 22(3): 867-880.

Nguy, T. M., Tran, T. T. & Tran, H. T. (2021). Effects of Drought Stress on Shoot Development of Tomato (*Solanum lycopersicum* L.). *Science and Technology Development Journal-Natural Sciences*, 5(2): 1208-1215.

Noreen, S., Fatima, K., Athar, H. U. R., Ahmad, S. & Hussain, K. (2017). Enhancement of Physio-Biochemical Parameters of Wheat Through Exogenous Application of Salicylic Acid under Drought Stress. *Journal of Animal and Plant Sciences*, 27(1): 153-163.

Peryea, F. J. & Kammereck, R. (1997). Use of Minolta SPAD-502 Chlorophyll Meter to Quantify the Effectiveness of Mid-Summer Trunk İnjection of Iron on Chlorotic Pear Trees. *Journal of Plant Nutrition*, 20(11): 1457-1463.

Rhaman, M. S., Imran, S., Rauf, F., Khatun, M., Baskin, C. C., Murata, Y. & Hasanuzzaman, M. (2020). Seed Priming with Phytohormones: An Effective Approach for the Mitigation of Abiotic Stress. *Plants*, 10(1): 37.

Salvi, P., Manna, M., Kaur, H., Thakur, T., Gandass, N., Bhatt, D. & Muthamilarasan, M. (2021). Phytohormone Signaling and Crosstalk in Regulating Drought Stress Response in Plants. *Plant Cell Reports*, 40(8): 1305-1329.

Sattar, A., Ul-Allah, S., Ijaz, M., Sher, A., Butt, M., Abbas, T. & Alharbi, S. A. (2021). Exogenous Application of Strigolactone Alleviates Drought Stress in Maize Seedlings by Regulating the Physiological and Antioxidants Defense Mechanisms. *Cereal Research Communications*, 1-10.

Sedaghat, M., Emam, Y., Mokhtassi-Bidgoli, A., Hazrati, S., Lovisolo, C., Visentin, I. & Tahmasebi-Sarvestani, Z. (2021). The Potential of the Synthetic Strigolactone Analogue GR24 for the Maintenance of Photosynthesis and Yield in Winter Wheat under Drought: Investigations on the Mechanisms of Action and Delivery Modes. *Plants*, 10(6): 1223.

Sedaghat, M., Tahmasebi-Sarvestani, Z., Emam, Y. & Mokhtassi-Bidgoli, A. (2017). Physiological and Antioxidant Responses of Winter Wheat Cultivars to Strigolactone and Salicylic Acid in Drought. *Plant Physiology and Biochemistry*, 119: 59-69.

Smart, R. E. & Bingham, G. E. (1974). Rapid Estimates of Relative Water Content. *Plant Physiology*, 53(2):258 260.

IAEPD, 2021. Institute of Agricultural Economics and Policy Development, https://l24.im/oE4kZq (Date of access: 19 April 2022).

TSI, 2020. Turkish Statistical Institute, https://data.tuik.gov.tr/Kategori/GetKategori?p=tarim-111&dil=1 (Date of access: 19 April 2022).

Van Ha, C., Leyva-González, M. A., Osakabe, Y., Tran, U. T., Nishiyama, R., Watanabe, Y. & Tran, L. S. P. (2014). Positive Regulatory Role of Strigolactone in Plant Responses to Drought and Salt Stress. *Proceedings of the National Academy of Sciences*, 111(2): 851-856.

Visentin, I., Pagliarani, C., Deva, E., Caracci, A., Turečková, V., Novák, O. & Cardinale, F. (2020). A Novel Strigolactone-miR156 Module Controls Stomatal Behaviour During Drought Recovery. *Plant, Cell and Environment*, 43(7): 1613-1624.

Wani, A. B., Chadar, H., Wani, A. H., Singh, S. & Upadhyay, N. (2017). Salicylic Acid to Decrease Plant Stress. *Environmental Chemistry Letters*,15: 101–123.

Wilson, P. J., Thompson, K. E. N. & Hodgson, J. G. (1999). Specific Leaf Area and Leaf Dry Matter Content as Alternative Predictors of Plant Strategies. *The New Phytologist*, 143(1): 155-162.

Xie, X., Yoneyama, K. & Yoneyama, K. (2010). The Strigolactone Story. *Annual Review of Phytopathology*, 48: 93-117.

Yang, Y., Gu, M., Chen, J., Zhang, R., Liu, Z., Shi, Y. & Wang, L. (2022). Comparative Transcriptomes Reveal the Mitigation Effect of GR24 in Alfalfa under Drought Stress. *Journal of Plant Growth Regulation*, 1-12.

Yanik, F., Aytürk, Ö., Çetinbaş-Genç, A. & Vardar, F. (2018). Salicylic Acid-Induced Germination, Biochemical and Developmental Alterations in Rye (*Secale cereale* L.). *Acta Botanica Croatica*, 77(1): 45-50.

Zhang, Z., Cao, B., Gao, S. & Xu, K. (2019). Grafting Improves Tomato Drought Tolerance Through Enhancing Photosynthetic Capacity and Reducing ROS Accumulation. *Protoplasma*, 256(4): 1013-1024.