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Determination of the Effects of Exogenous Gibberellic Acid on Melon (*Cucumis melo* L.) Under Drought Stress

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Abstract: This study aimed to investigate the effects of drought stress on melon (*Cucumis melo* L.) and to evaluate the potential mitigating role of gibberellic acid (GA_3) application. In the experiment, a 10-day drought period was imposed by withholding irrigation, and GA_3 was applied at a concentration of 100 ppm. The results indicated that drought stress significantly suppressed plant growth. The SPAD value decreased by 26%, from 303.6 ± 8.9 in the control group to 224.1 ± 5.9 under drought conditions, while GA_3 application did not lead to a statistically significant improvement. Drought stress increased malondialdehyde levels from 3.6 to 7.9, whereas GA_3 treatment reduced it to 5.67, indicating a partial alleviation of oxidative stress. Root length decreased from 50 ± 8.1 cm in the control to 31 ± 5.09 cm under drought stress and was further reduced to 25 ± 6.03 cm with GA_3 application. Principal Coordinate Analysis revealed that GA_3 application did not completely mitigate drought stress but provided partial improvement. These findings highlight the detrimental effects of drought stress on melon and indicate that GA_3 alone may not be sufficient to alleviate drought-induced damage in melon cultivation.

Keywords: Melon, abiotic stress, plant growth regulator, SPAD

1. Introduction

The rapid expansion of urbanization, industrialization, and transportation has led to a continuous reduction in arable land, further aggravated by global climate change, water scarcity, and a rise in both biotic and abiotic stress factors. Among these, drought represents one of the most critical abiotic stressors, severely affecting plant growth, development, and yield potential. Global agricultural losses due to drought are estimated to reach up to 30% annually (Grafton et al., 2015). Drought stress impairs plant performance primarily by reducing water availability at the cellular, tissue, and organ levels, thereby disrupting essential physiological and metabolic activities (Farooq et al., 2009). In response, plants have evolved adaptive mechanisms such as enhanced root water uptake, stomatal closure to reduce transpiration, and activation of biochemical defense pathways (Fang and Xiong, 2015). A central component of this response is stomatal regulation, which conserves water by controlling gas exchange. However, prolonged stomatal closure restricts carbon dioxide (CO_2) assimilation, lowers photosynthetic efficiency, and ultimately limits biomass accumulation (Ahmed et al., 2007).

Additionally, drought stress promotes excessive production of reactive oxygen species (ROS), leading to oxidative damage through lipid peroxidation, protein degradation, and DNA damage, ultimately disrupting photosynthetic machinery and cellular homeostasis (Möller et al., 2007). Given the increasing frequency and intensity of drought events globally, developing efficient strategies to enhance drought tolerance has become a pressing need in sustainable agriculture. Two major strategies for improving drought resilience involve (i) the breeding of high-yielding, drought-tolerant cultivars, and (ii) the implementation of agronomic or biochemical interventions to support plant performance under water-deficient conditions. Notably, substantial variability exists not only across plant species but also among genotypes within a species in response to drought, emphasizing the importance of genotype-specific tolerance mechanisms (Jaleel et al., 2009). Comprehensive characterization of these mechanisms is vital for the development of resilient cultivars and the advancement of sustainable production systems (Pourghayoumi et al., 2017).

Among the biochemical strategies, the use of plant growth regulators (PGRs) has emerged as a promising tool to alleviate stress-induced damage. PGRs are natural or synthetic substances that, even at low concentrations, regulate plant development, metabolism, and stress responses (Kaur and Kaur, 2016). One such regulator, gibberellic acid (GA_3), has been shown to improve plant tolerance to drought stress by enhancing cell division and elongation, sustaining photosynthetic efficiency, and modulating antioxidant enzyme systems (Shah et al., 2023). Exogenous application of GA_3 has demonstrated positive effects on plant growth, biomass accumulation, and physiological performance under various stress conditions (Doruk Kahraman and Okumuş, 2024). Nevertheless, the specific role of GA_3 in mitigating drought stress in melon (*Cucumis melo* L.) remains poorly understood.

Melon is an economically important horticultural crop cultivated across a wide range of agroclimatic zones. Despite moderate salinity tolerance, it is highly sensitive to water deficit, particularly during early developmental stages, which can result in substantial yield reductions under drought stress (Sarabi et al., 2017). Research on PGR applications under drought conditions in melon is limited, necessitating further investigation. This study aims to explore the physiological and morphological responses of melon plants under drought conditions and to assess the potential mitigating effects of GA_3. By evaluating key growth and biochemical parameters, this research will provide insights into drought stress tolerance mechanisms in melon and inform strategies to enhance its resilience under water-limited environments. We hypothesize that GA_3 application will alleviate drought-induced damage by improving plant growth and physiological functions, thereby enhancing drought tolerance in melon.

2. Materials and Methods

The experiment was conducted in the greenhouse facilities of Hatay Mustafa Kemal University during the spring growing season of 2024, using the melon cultivar ‘Anka F1’. Melon (*C. melo*) seeds were surface-sterilized with 5% sodium hypochlorite for 10 minutes, rinsed thoroughly with sterile distilled water, and sown in soil containing 54% organic matter (pH 5.5–6.8; Mixflor). Seedlings were grown under controlled greenhouse conditions until they reached approximately 15 cm in height. Drought stress was imposed by withholding irrigation for 10 days following the six-expanded-leaf stage, simulating field-relevant stress conditions (Coşkun, 2023, 2025). The experiment was laid out in a completely randomized design with treatment groups. Gibberellic acid was applied as a foliar spray at a concentration of 100 ppm one day prior to the onset of drought stress, using Tween-20 as a surfactant, based on the application method described by Tuna et al. (2008).

The experiment was conducted in a completely randomized design with three biological replicates. Each replicate consisted of five pots, with one plant per pot. Morphological parameters such as root length, plant height, stem diameter, and leaf number were measured using a ruler and digital caliper. Fresh biomass was determined immediately after harvest. Dry biomass was recorded after drying samples at 70 °C for 48 hours in a forced-air oven. Chlorophyll content (SPAD) was measured using a Minolta SPAD-502 meter on the fourth fully expanded leaf. Photosynthetically active radiation (PAR) was measured with a Mini PPM 100 fluorimeter (EARS, Netherlands).

Lipid peroxidation levels were quantified using the thiobarbituric acid reactive substances (TBARS) assay. Leaf samples (0.2 g) were homogenized in 1% trichloroacetic acid (TCA), followed by centrifugation at 10.000×g for 5 minutes. The supernatant was then mixed with 20% TCA containing thiobarbituric acid (TBA), incubated at 95 °C for 30 minutes, cooled, centrifuged again, and the absorbance of the resulting supernatant was measured at 532 nm.

Statistical analyses included Pearson correlation ($p<0.05$, $p<0.01$) to evaluate associations among traits, visualized using heatmaps. Principal Coordinates Analysis (PCoA) was performed using Bray-Curtis or Euclidean distance matrices, with Z-score normalization applied beforehand. One-way analysis of variance (ANOVA) was used to assess significant differences among treatment groups, followed by Tukey’s HSD test ($p= 0.05$) for multiple comparisons. All statistical analyses were conducted using SPSS version 22, and results were presented as mean ± standard error (SE).

3. Results

SPAD values, which reflect leaf chlorophyll content and photosynthetic potential, were significantly affected by drought stress. In the control group, the SPAD value was 60.7 ± 8.9, while it increased to

66.4 ± 3.5 with GA_3 application, indicating that GA_3 may enhance chlorophyll synthesis under non-stress conditions. Under drought stress, the SPAD value dropped significantly to 44.8 ± 5.9 ($p<0.05$), representing a 26% reduction. In the drought + GA_3 treatment, the SPAD value was 44.6 ± 8.8, showing no statistically significant recovery compared to drought alone, suggesting that GA_3 did not mitigate chlorophyll loss under stress. Measurements of PAR showed 69.4 ± 0.87 in the control group and 67.0 ± 1.58 in the GA_3-treated group, with no significant difference between them. Drought stress caused a decrease in PAR to 57.9 ± 4.71, and although GA_3 application increased it slightly to 60.67 ± 8.25, the difference was not statistically significant ($p>0.05$). This indicates that GA_3 application alone may not directly enhance photosynthetic efficiency under drought conditions. Malondialdehyde (MDA) is one of the most commonly used biomarkers for lipid peroxidation. Malondialdehyde, a key indicator of oxidative stress, was 3.6 ± 0.24 in both the control and control + GA_3 groups, suggesting that GA_3 does not induce oxidative damage under optimal conditions. In the drought-stressed group, MDA levels significantly increased to 7.9 ± 0.38 ($p<0.05$), confirming elevated membrane lipid peroxidation. However, in the drought + GA_3 treatment, MDA levels were reduced to 5.67 ± 0.33, indicating that GA_3 can partially alleviate oxidative damage under drought conditions (Table 1).

In the control group, root length was measured as 50 ± 8.1 cm, while it slightly decreased to 45 ± 5.77 cm with GA_3 application under non-stress conditions. Drought stress significantly reduced root length to 31 ± 5.09 cm ($p<0.05$), and the application of GA_3 under drought conditions further decreased it to 25 ± 6.03 cm (Table 2). These findings suggest that drought severely limits root development and that GA_3 application fails to mitigate this effect. Similarly, plant height declined from 111.8 ± 9.76 cm in the control group to 93.6 ± 6.67 cm with GA_3 application under normal conditions. Drought stress resulted in a significant reduction to 65.5 ± 4.39 cm, and the drought + GA_3 group exhibited an even lower height of 52.67 ± 1.33 cm (Table 2). These results indicate that GA_3 is not effective in reversing drought-induced growth inhibition in melon plants. Stem diameter showed no statistically significant differences among treatments ($p>0.05$). The mean values were 4.75 ± 2.41 mm in the control group, 4.65 ± 1.01 mm in control + GA_3, 4.26 ± 1.81 mm in drought-stressed plants, and 4.12 ± 1.16 mm in the drought + GA_3 group (Table 2). These findings suggest that neither drought stress nor GA_3 application had a considerable impact on stem thickness.

In the control group, the number of leaves was 12.6 ± 0.4, while it slightly decreased to 11.6 ± 0.51 in the control + GA_3 group, indicating a minor reduction under normal conditions ($p>0.05$). Drought stress caused a significant decline in leaf number to 5.4 ± 0.22 ($p<0.05$), corresponding to a 57% reduction. In the drought + GA_3 group, leaf number increased slightly to 6.33 ± 0.67, indicating a limited improvement; however, this increase was not statistically significant compared to the drought-only group. Fresh weight was recorded as 1520.4 ± 287.2 g in the control group and 1452 ± 320.3 g in the control + GA_3 group, showing no significant difference between the two ($p>0.05$). Drought stress markedly reduced fresh weight to 666.4 ± 36.9 g, and further reduction was observed in the drought + GA_3 group (543 ± 83.9 g) (Table 3). These findings suggest that GA_3 application did not effectively maintain biomass production under drought conditions. Similarly, dry weight

Table 1. The effect of drought stress and GA_3 application on SPAD, PAR, and MDA values in melon plants (M±SE)

Treatments	SPAD	PAR	MDA
Control	60.7 ± 8.9 b	69.4 ± 0.87 a	3.6 ± 0.24 c
Control+GA_3	66.4 ± 3.5 a	67.0 ± 1.58 a	3.6 ± 0.24 c
Drought	44.8 ± 5.9 c	57.9 ± 4.71 a	7.9 ± 0.38 a
Drought+GA_3	44.6 ± 8.8 c	60.67 ± 8.25 a	5.67 ± 0.33 b
Mean	54.1 ± 6.8	62.74 ± 2.45	5.74 ± 0.46

Table 2. The effect of drought stress and GA_3 application on root length, plant height, and stem diameter in melon plants (M±SE)

Treatments	Root length (cm)	Plant height (cm)	Stem diameter (mm)
Control	50 ± 8.10 a	111.8 ± 9.76 a	4.75 ± 2.41 a
Control+GA_3	45 ± 5.77 ab	93.6 ± 6.67 a	4.65 ± 1.01 a
Drought	31 ± 5.09 ab	65.5 ± 4.39 b	4.26 ± 1.81 a
Drought+GA_3	25 ± 6.03 b	52.67 ± 1.33 b	4.12 ± 1.16 a
Mean	37.39 ± 3.58	80 ± 5.42	4.43 ± 1.06

Table 3. The effect of drought stress and GA₃ application on leaf number, fresh weight, and dry weight in melon plants (M±SE)

Treatments	Leaf number	Fresh weight (g)	Dry weight (g)
Control	12.6 ± 0.40 a	1520.4 ± 287.2 a	248.6 ± 16.5 a
Control+GA$_3$	11.6 ± 0.51 a	1452 ± 320.3 a	180 ± 16.4 b
Drought	5.4 ± 0.22 b	666.4 ± 36.9 b	85.3 ± 5.9 c
Drought+GA$_3$	6.33 ± 0.67 b	543 ± 83.9 b	73.67 ± 5.6 c
Mean	8.43 ± 0.71	1006.74 ± 161.68	139.87 ± 15.67

significantly declined from 248.6 ± 16.5 g in the control group to 85.3 ± 5.9 g under drought stress ($p<0.05$), representing a 66% reduction. In the drought + GA$_3$ group, dry weight was measured as 73.67 ± 5.6 g, indicating that GA$_3$ was not effective in preventing the drought-induced loss of structural biomass (Table 3).

Correlation analysis revealed significant associations among plant growth traits, physiological indicators, and stress-related markers. A strong positive correlation was observed between plant height and root length (r= 0.85), suggesting coordinated development of shoot and root systems. Plant height also correlated positively with fresh weight (r= 0.86) and dry weight (r= 0.83), underscoring its central role in biomass accumulation. SPAD values showed a strong negative correlation with MDA levels (r= -0.76), indicating that elevated oxidative stress, as reflected by increased MDA, is associated with reduced chlorophyll content and impaired photosynthetic capacity. Similarly, MDA was negatively correlated with both fresh weight (r= -0.78) and dry weight (r= -0.74), highlighting the contribution of oxidative damage to biomass loss under drought conditions (Figure 1). In GA$_3$-treated plants, lower MDA levels and higher SPAD values suggest a potential role of GA$_3$ in alleviating oxidative stress and partially supporting physiological performance. These results provide valuable insights into the interplay between physiological traits and stress responses, contributing to the development of targeted strategies for improving drought resilience in crops.

Principal Coordinate Analysis was conducted to assess the impact of different treatments (Control, GA$_3$, drought, and GA$_3$ + drought) on plant growth, physiological performance, and stress-related traits. The PCoA plot revealed a distinct separation among the treatment groups based on their multivariate profiles. The control group, representing optimal growth and physiological conditions, was positioned furthest from all stress-associated groups, indicating maximal performance in the

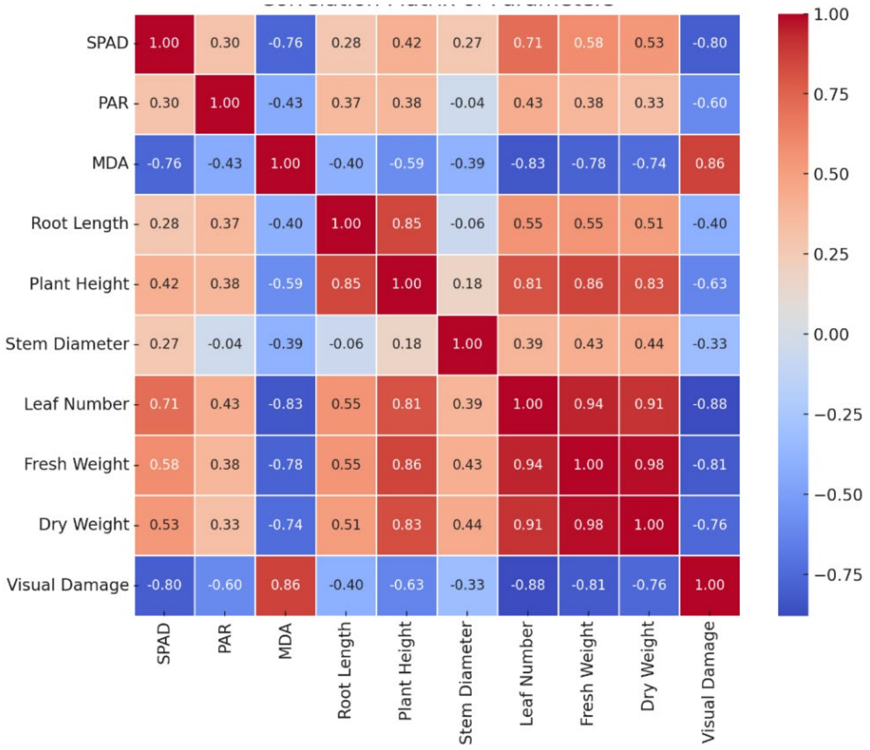

Figure 1. Correlation matrix of parameters

absence of stress. Conversely, the drought group formed a clearly isolated cluster, reflecting pronounced impairment in growth and physiological responses. GA_3-treated plants under non-stress conditions clustered closer to the control group, supporting the enhancing effect of GA_3 on growth parameters. In contrast, the GA_3 + drought group was positioned closer to the drought cluster, suggesting that GA_3 application did not fully counteract the effects of drought but may confer partial tolerance (Figure 2). Overall, the PCoA results confirm that drought stress substantially alters plant physiological status, and while GA_3 application offers some mitigation, its protective effect appears limited under severe stress conditions. Further validation through hormonal profiling, gene expression analysis, and extended physiological monitoring is recommended.

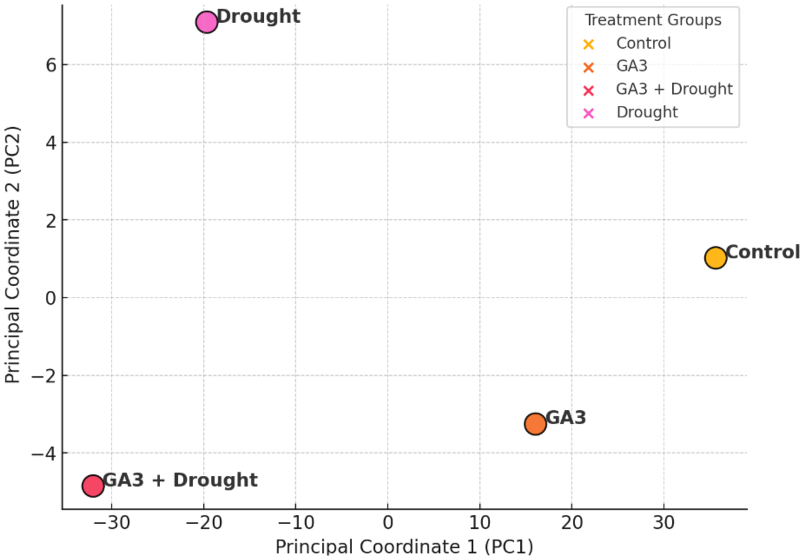

Figure 2. Principal Coordinate Analysis (PCoA)

4. Discussion and Conclusion

Drought stress is well-recognized for its multifaceted impact on plant systems, influencing morphology, physiology, and gene regulation, especially during early developmental stages when plants are most vulnerable (Giordano et al., 2021). In this study, melon genotypes subjected to drought exhibited substantial reductions in growth-related parameters, aligning with prior research that underscores the sensitivity of cucurbits to water deficit (Mohamed et al., 2021; Gebril and Elsayed, 2025). The root system, as the primary interface for water uptake, is particularly affected, and its compromised development under stress is a key limiting factor in overall plant performance (Karahara and Horie, 2021).

Photosynthetic capacity, one of the earliest physiological traits to decline under drought, was notably suppressed in this study, as reflected by reduced SPAD and PAR values. These observations are consistent with earlier findings indicating that drought-induced stomatal closure and chlorophyll degradation reduce light absorption and CO_2 assimilation (Nankishore and Farrell, 2016; Zhou et al., 2017). SPAD values were negatively correlated with MDA accumulation, further confirming the link between oxidative stress and diminished photosynthetic activity. Lipid peroxidation, measured by MDA content, significantly increased under drought, corroborating the hypothesis that water deficit leads to the overproduction of ROS and oxidative membrane damage (Farooq et al., 2009). These biochemical responses represent a major bottleneck in stress tolerance and underscore the necessity for effective protective mechanisms.

Gibberellic acid, a widely studied plant growth regulator, is known to modulate abiotic stress responses by promoting cell division, maintaining chlorophyll levels, and enhancing antioxidant defenses (Shah et al., 2023). In this study, GA_3 application under drought conditions resulted in reduced MDA levels and marginal improvements in growth traits such as leaf number and dry weight, suggesting partial protection. These findings are in line with previous reports demonstrating that exogenous GA_3 can alleviate oxidative damage and maintain photosynthetic stability (Wu et al., 2019; Imran et al., 2021). However, the inability of GA_3 to fully restore physiological performance under severe drought indicates that its protective effects may be dose- or timing-dependent, or that it is insufficient alone to overcome the combined limitations imposed by water scarcity and oxidative stress. It is also possible that GA_3's effects are more pronounced in early stages of stress perception rather than during prolonged stress exposure. This opens the door for investigating the spatiotemporal dynamics of GA_3 signaling in stress regulation.

This study demonstrated that drought stress severely impairs physiological and morphological traits in melon, while exogenous GA_3 application provides only limited mitigation. Although GA_3 treatment reduced oxidative stress markers such as MDA, it did not significantly improve key growth indicators such as biomass or root development under drought conditions. These findings suggest that GA_3 alone is insufficient to protect melon plants from the multifactorial impact of water deficit. The results indicate that GA_3 may serve as a supportive tool but should not be considered a standalone strategy for drought mitigation in melon cultivation. While the hormone was applied at a validated concentration and using a foliar method supported by prior studies, its limited performance under drought may reflect physiological constraints such as stomatal closure and turgor loss, which impair hormone uptake and action. In addition, the plant's response to exogenous GA_3 is often highly context-dependent, influenced by genotype, developmental stage, and timing of application relative to stress exposure. These factors may have contributed to the observed modest impact on growth traits despite a measurable reduction in oxidative damage. Integrating GA_3 with other physiological or agronomic approaches-such as antioxidant priming, biostimulant use, or drought-tolerant rootstocks-may enhance overall stress resilience. Further research should explore dose optimization and application timing to maximize GA_3's potential. This study contributes to a better understanding of hormone-mediated stress responses in melon and provides a basis for future efforts in stress management strategies under water-limited environments.

Ethical Statement

The authors declare that ethical approval is not required for this research.

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Declaration of Author Contributions

Conceptualization, Material, Methodology, Investigation, Data Curation, Visualization, Writing-Original Draft Preparation, Writing-Review & Editing, *S. TOPRAK*; Data Curation, Formal Analysis, Writing-Review & Editing, *Ö.F. COŞKUN*. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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