Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1887190

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 9 - Issue 3 : 345-352 / May 2026

REGULATORY EFFECTS OF PACLOBUTRAZOL TREATMENT ON GROWTH AND DEVELOPMENT OF *Dahlia × hybrida* AND *Matthiola incana* SEEDLINGS

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Abstract: Plant growth retardants are widely used in ornamental plant production to control excessive vegetative growth, enhance compactness, and improve overall seedling quality. This study aimed to evaluate the regulatory effects of different paclobutrazol (PBZ) doses on seedling morphology, biomass accumulation, and chlorophyll index in *Dahlia × hybrida* and *Matthiola incana.* Although the effects of PBZ on growth and physiology have been reported for various ornamental species, information on morphological responses and biomass distribution during the seedling stage in dahlia and stock remains limited. Seeds of *Dahlia × hybrida* 'Figaro' and *Matthiola incana* StoX® were sown in 384-cell trays filled with a peat: perlite (2:1, v/v) substrate and grown in a ventilated greenhouse. Following the emergence of the first true leaves, PBZ was applied as a foliar spray at concentrations of 2, 4, 8, 12, and 16 ppm (control: distilled water). Measurements were conducted 40 days after treatment. Seedling height, stem diameter, leaf number, shoot and root fresh and dry weight, root length, and SPAD values were evaluated using a completely randomized design. PBZ treatments significantly affected seedling growth parameters in both species, with species-specific responses to increasing doses (P<0.001). In dahlia seedlings, 4 ppm PBZ was generally associated with more balanced growth responses, including higher shoot biomass and leaf number, whereas higher doses tended to limit biomass accumulation. In stock seedlings, increasing PBZ doses were associated with reduced seedling height, while higher doses showed higher SPAD values and root length; however, root fresh and dry weights tended to decrease at elevated PBZ concentrations. Overall, the results suggest that PBZ dose optimization is critical for achieving compact growth while maintaining seedling quality, and that species-specific responses should be considered when determining appropriate treatment rates.

Keywords: *Dahlia* x *hybrida*, *Matthiola incana*, Seedling, Triazole, Growth regulator

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Received: February 11, 2026
Accepted: March 16, 2026
Published: May 15, 2026

Cite as: Alkaç, O. S. (2026). Regulatory effects of paclobutrazol treatment on growth and development of *Dahlia × hybrida* and *Matthiola incana* seedlings. *Black Sea Journal of Agriculture*, 9(3): 345-352.

1. Introduction

Plant growth regulators are compounds that can be obtained from microorganisms or synthesized and have physiological effects similar to those of plant hormones. These compounds are classified into three main groups: growth promoters, growth inhibitors, and growth retardants (Martínez-Damián et al., 2019). Within these groups, the use of plant growth retardants is a commonly employed method for controlling plant development (Wu et al., 2022). When applied at low doses, they limit plants from reaching their expected height; however, plant growth does not completely stop because there is no significant decrease in cell number during the dwarfing process. Thanks to these properties, plant growth retardants offer a highly suitable approach for large-scale treatments. Paclobutrazol (PBZ), an important plant growth retarder in horticulture, suppresses vegetative growth (Ghosh et al., 2010; Sun et al., 2010; Orozco-Meléndez et al., 2022), promotes reproductive growth (Esmaielpour et al., 2011; Mukadam and Haldankar, 2013; Xu et al., 2013), and increases plant resistance to stress conditions (Srivastav et al., 2010; Baninasab and Ghobadi, 2011; Zhou et al., 2012). PBZ is a chemical with high biological activity and is effective on many plant species when applied as a spray or soil drench (Barrett, 2001). PBZ suppresses gibberellic acid (GA) biosynthesis by inhibiting ent-kaurenoyl oxidation (Sponsel, 1995). It is widely used in the floriculture industry to control plant size and improve plant quality (Million et al., 1999). It is generally applied at a dose range of 1–90 mg L^{-1} in perennial plants and other potted plants (Barrett, 2001). When applied as a foliar spray, PBZ is absorbed by leaf stalks and stems and transported to growth points via the xylem. When applied by soil drenching, it is taken up by the roots and transported to the apical meristems via the xylem (Desta and Amare, 2021). The soil drench method may be more effective than foliar spray treatments in terms of increasing the level of effect and reducing the risk of excessive dwarfing and delayed flowering, as it does not come into direct contact with flowers or flower buds (Million et al., 1999). Studies investigating the effects of PBZ on growth, morphological characteristics, and some physiological–biochemical parameters in ornamental plants include *Rosa damascena* (Misra et al., 2005), *Lilium* oriental hybrids 'Sorbonne' (Zheng et al., 2012), *Stevia rebaudiana* (Hajihashemi and Ehsanpour, 2013; 2014), and *Helianthus annuus* (Koutroubas and Damalas, 2015). Compact seedlings are associated with a sturdier stem that reduces the risk of breakage/lodging and better "handling" (manual/mechanical holding–transportation) characteristics; this is one of the key indicators of seedling quality (Latimer, 1998; Agehara and Leskovar, 2014). Excessive stem elongation can reduce holding success in field/greenhouse conditions and can make mechanical transplanting particularly difficult; methods such as mechanical conditioning have been shown to improve seedling quality by controlling height (Garner and Björkman, 1999). Height control approaches (e.g., certain treatments) can improve seedling quality by altering morphology (e.g., more appropriate root–stem balance, reducing water loss/preserving quality); this is a framework associated with post-transplanting performance (Agehara and Leskovar, 2017). Growth regulators that limit excessive elongation under dense planting conditions have been reported to be effective on seedling architecture/dimensions (Zhou et al., 2022). It has been compiled at both the treatment and mechanism levels that plants respond to mechanical stimuli (wind, touch, brushing, etc.) by reducing elongation and growing more compactly; this can be used in seedling height control (Latimer, 1998; Telewski, 2016). However, there is limited information in the literature regarding the effects of PBZ on the physiological activity and seedling quality of *Dahlia variabilis* and *Matthiola incana* in seedling cultivation.

Dahlia (*Dahlia ×hybrida*) is a common annual ornamental plant that holds an important place in modern ornamental plant cultivation and the landscaping industry due to the wide variety of colors and forms it offers for landscaping. In recent years, potted dahlias have been gaining increasing attention in both container and landscape design due to their aesthetic value, versatility, and ability to easily adapt to different landscape treatments (Schneck et al., 2021). *Matthiola incana* L. is one of the most important cut flowers widely cultivated for its fragrance, beautiful shape, and color variety (Sánchez et al., 2005; Irani and Arab, 2017). It is a species of the Brassicaceae family and is generally found in two forms: single-flowered and double-flowered; the latter is more popular in the market (Eid et al., 2009; Jafari et al., 2019).

This study was conducted to determine the effectiveness of paclobutrazol (PBZ) in controlling problems commonly encountered in ornamental plant seedling production, such as excessive elongation, weak stem development, and low seedling quality. Dahlia and stock were selected because they differ in growth rates and morphological characteristics during the seedling stage, and there is a clear need for compact, robust, and marketable seedlings in commercial production. In this context, the responses of both species to different PBZ doses during their development from seed to seedling stage were evaluated. The expected effects of PBZ, such as limiting seedling height, increasing stem thickness, regulating biomass distribution, and improving physiological performance (e.g., SPAD/chlorophyll level), were tested through morphological and biomass-based parameters. Thus, by determining species-specific responses, the aim was to contribute to the development of the optimal PBZ dose and treatment strategy in seedling cultivation.

2. Materials and Methods

2.1. Plant Material and Growing Conditions

In this study, two different species, *Dahlia x hybrida* and *Matthiola incana*, were used as plant material. *Dahlia x hybrida* 'Figaro' seeds were obtained from Tasaco Seed Co., Ltd. in Antalya, Türkiye, and *Matthiola incana* StoX® seeds were obtained from Sakata Seed Co., Ltd. in Yokohama, Japan. Seeds were sown on June 25 in 384-cell inserts containing a 2:1 peat: perlite mixture. The initial pH of the growing medium ranged from 5.8 to 6.2, and the electrical conductivity (EC) ranged from 0.6 to 0.8 dS m^{-1}. The plants were irrigated from above with moderately diluted water-soluble fertilizer (WS NPK 20+20+20+TE; VAN IPEREN B.V. Netherlands Co., Ltd., Rotterdam, Netherlands) when necessary. The fertilization amount was determined as EC 1.5 dS m^{-1}.

The study was conducted in a glass greenhouse with side and top ventilation, located at the Agricultural Research and Treatment Center of Tokat Gaziosmanpaşa University, and was not heated or cooled. During the experiment, plants were grown under natural light conditions, with greenhouse temperatures ranging from 26–28 °C during the day and 16–18 °C at night, and relative humidity averaging 60–70% (HOBO U12 Temp/RH/Light External Data Logger (U12-012)). Irrigation was carried out according to plant needs, and care was taken to maintain moisture and prevent the growing medium from drying out.

2.2. Study Plan and Treatments

2.2.1. Preparation of paclobutrazol (PBZ) solutions

The paclobutrazol (PBZ) used in this study was prepared from a commercial formulation (Cultar 25 SC, 250 g L^{-1} a.i. Syngenta Co., Ltd., Basel, Switzerland). Sixteen milliliters of the formulation were diluted to 1 L with distilled water to obtain a 4000 mg L^{-1} intermediate stock solution. From this intermediate stock solution, specified volumes were taken to obtain different PBZ doses, and each was diluted to 1 L with distilled water to prepare the final treatment solutions. Accordingly, solutions prepared by taking 0.50, 1.0, 2.0, 3.0, and 4.0 mL L^{-1} from the intermediate stock solution, respectively, corresponded to final paclobutrazol concentrations of 2, 4, 8, 12, and 16 ppm. The selection of PBZ doses was guided by information obtained from commercial ornamental seedling producers regarding species-specific treatment practices. Subsequently, these commercially relevant doses were systematically modified to establish a range of PBZ treatments suitable for evaluating seedling growth responses under controlled conditions. Only distilled water was used in the control group. All solutions were freshly prepared before treatment and thoroughly mixed to ensure homogeneity.

2.2.2. Timing and method of paclobutrazol treatment

Paclobutrazol (PBZ) was applied 15 days after seed sowing, corresponding to the stage at which the first true leaves had fully emerged following the cotyledon stage. PBZ was applied as a foliar spray using a hand-held pressure sprayer (1 L capacity) equipped with a fine mist nozzle to ensure uniform droplet distribution. Each seedling received approximately 10 mL of solution per plant, corresponding to a spray volume sufficient to achieve uniform leaf surface coverage without visible runoff. Care was taken to avoid excessive leaf drip to prevent uneven dose exposure. Treatments were carried out early in the morning (08:00) or late in the evening (18:00) to minimize environmental stress. In this study, six treatments were evaluated during the seedling stage: five PBZ doses (2, 4, 8, 12, and 16 ppm) and one control treatment (distilled water).

2.3. Measurement of Growth Parameters

Growth parameter measurements were performed 40 days after paclobutrazol (PBZ) treatment. Measurements were taken before and during plant harvest, considering the morphological and physiological parameters listed below.

2.3.1. Seedling height (cm)

Seedling height was measured from the insert surface to the top of the plant using a ruler, and the obtained values were recorded in centimeters (cm).

2.3.2. Stem diameter (mm)

Stem diameter was measured approximately 1 cm above the insert surface using a digital caliper, and the results were expressed in millimeters (mm).

2.3.3. Number of leaves (per seedling^{-1})

The number of fully developed leaves on each seedling was counted to determine the number of leaves per seedling.

2.3.4. Seedling fresh weight (g)

After harvesting the above-ground parts of the seedlings and removing surface moisture, they were weighed using a precision balance and recorded as fresh weight (g).

2.3.5. Dry weight of seedlings (g)

Above-ground specimens were dried in an oven at 65°C until a constant weight was reached, and then their dry weight (g) was determined.

2.3.6. Root length (cm)

Roots were carefully washed to remove adhering soil particles, and the length of the longest root was measured using a ruler and recorded in centimeters (cm).

2.3.7. Fresh and dry weight of roots (g)

The fresh weights of the washed roots were measured using a precision balance. The roots were then dried at 65°C until constant weight was achieved, and the dry root weight (g) was determined.

2.3.8. SPAD value

Leaf chlorophyll content was determined using a portable chlorophyll meter, the SPAD-502 (Konica Minolta, Japan). Three measurements were taken from fully developed leaves in the middle of each plant, and the average was calculated as the plant's SPAD value. SPAD values have been widely accepted in plant growth and stress physiology studies and have been used as indicators of leaf chlorophyll content and photosynthetic potential (Markwell et al., 1995; Uddling et al., 2007).

2.4. Statistical Analysis

The study plan was designed using a completely randomized design (CRD). The study was conducted with 3 replications, each containing 10 seedlings. The data obtained were analyzed using SPSS 22.0 (IBM Corp., Armonk, NY, USA). The interaction between varieties and dose was statistically tested using a factorial ANOVA. Duncan's multiple-comparison test was used to determine differences between the means. The statistical significance level was set at $P \leq 0.05$. Results are presented as mean ± standard error (ME ± SE), and graphs were created according to the statistical analysis results.

3. Results

The factorial ANOVA revealed that most of the evaluated traits were significantly affected by species, PBZ dose, and their interaction (Table 1). Species had a strong influence on seedling height, stem diameter, shoot fresh weight, root parameters, and SPAD values. PBZ dose significantly affected seedling height, leaf number, shoot fresh weight, shoot dry weight, and SPAD. Furthermore, significant species × dose interactions were observed for most growth-related parameters, indicating that the response to PBZ application differed between the two species.

The effects of different PBZ doses on the growth and development characteristics of dahlia and stock seedlings are presented in Figure 1. It was determined that PBZ treatments had statistically significant effects on seedling height, seedling fresh weight, and seedling dry weight in both species ($P<0.001$). Statistically significant differences in seedling height were observed between PBZ treatments both within and between species ($P<0.001$). The highest seedling height in dahlia seedlings was obtained with a 4 ppm PBZ treatment (18.27 cm), while the lowest seedling height was determined with a 12 ppm PBZ treatment. In stock seedlings, a clear decrease in seedling height was observed with increasing PBZ dose. The highest seedling height was obtained in the control treatment (19.33 cm), while the lowest seedling height (8.88 cm) was determined in the 16 ppm PBZ treatment. When comparing the species, dahlia seedlings were taller than stock seedlings at all PBZ doses. The effect of PBZ treatments on seedling fresh weight was statistically significant in both species (P<0.001). The highest fresh weight in dahlia seedlings was observed with the 4 ppm PBZ treatment (10.37 g), which was statistically higher than the other treatments. A decrease in seedling fresh weight was observed at high PBZ doses (especially 12 ppm). In seedlings in stock, PBZ treatments caused a more limited change in fresh weight.

Table 1. Two-way ANOVA summary showing F values and degrees of freedom for species, PBZ dose, and species × dose interaction effects

Parameter	Factor	df	F	P	Parameter	Factor	df	F	P
Seedling Height	Species	1.24	113.68	<0.001	Root Length	Species	1.24	12.64	0.002
	Dose	5.24	27.70	<0.001		Dose	5.24	1.30	0.299
	Species × Dose	5.24	11.29	<0.001		Species × Dose	5.24	0.61	0.694
Stem Diameter	Species	1.24	32.15	<0.001	Root Fresh Weight	Species	1.24	15.50	0.001
	Dose	5.24	2.32	0.075		Dose	5.24	1.16	0.357
	Species × Dose	5.24	10.90	<0.001		Species × Dose	5.24	5.06	0.003
Leaf Number	Species	1.24	5.75	0.025	Root Dry Weight	Species	1.24	27.94	<0.001
	Dose	5.24	7.03	<0.001		Dose	5.24	1.78	0.155
	Species × Dose	5.24	6.66	0.001		Species × Dose	5.24	3.76	0.012
Seedling Fresh Weight	Species	1.24	50.04	<0.001	SPAD	Species	1.24	254.67	<0.001
	Dose	5.24	4.54	0.005		Dose	5.24	13.93	<0.001
	Species × Dose	5.24	2.62	0.050		Species × Dose	5.24	4.66	0.004
Seedling Dry Weight	Species	1.24	0.03	0.854					
	Dose	5.24	3.57	0.015					
	Species × Dose	5.24	3.88	0.010					

The highest fresh weight values were obtained with the 2 and 4 ppm PBZ treatments, while the lowest values were observed in the control and the 16 ppm PBZ treatments. In the inter-species comparison, it was determined that the fresh weight values of dahlia seedlings were higher than those of stock seedlings at all PBZ doses. PBZ treatments had a statistically significant effect on seedling dry weight in both species (P<0.001). The highest dry weight value in dahlia seedlings was obtained with the 4 ppm PBZ treatment (0.87 g), followed by the 2 and 8 ppm PBZ treatments.

The effects of different PBZ doses on root development parameters in dahlia and stock seedlings are presented in Figure 2. PBZ treatments were found to have statistically significant differences on root fresh weight and root dry weight depending on the species (P<0.001). The highest root length in dahlia seedlings was observed at 12 ppm PBZ treatment (11.00 cm), while the lowest (9.27 cm) was observed in the control group. In stock seedlings, the highest root length was determined in the 8 ppm PBZ treatment (13.77 cm), and the lowest root length (10.05 cm) was determined in the control treatment. When species were compared, it was determined that stock seedlings developed longer roots than dahlia seedlings at all PBZ doses. The effects of PBZ treatments on root dry weight differed between species. Root fresh weight in dahlia seedlings increased significantly with PBZ treatments. The highest values were obtained with 4 ppm (2.21 g) and 16 ppm PBZ (2.20 g) treatments. In stock seedlings, the highest value was determined in the control group (1.52 g), and the values decreased after PBZ treatments. Root dry weight remained low, especially at 4, 8, and 16 ppm. In the interspecific comparison, it was noted that PBZ treatments increased root biomass in dahlia but inhibited it in stock. PBZ treatments produced different responses on root dry weight in dahlia and stock species. The highest root dry weight in dahlia seedlings was obtained with 4 ppm PBZ treatment (0.153 g), and dry matter accumulation increased, especially at low and medium doses, compared with the control group. In stock seedlings, the highest root dry weight was observed in the control treatment (0.101 g), while the lowest was observed in the 16 ppm PBZ treatment (0.463 g). When comparing the species, it was determined that dahlia seedlings accumulated more root dry matter than stock seedlings, especially at the 4 ppm PBZ dose.

The effects of different PBZ doses on stem diameter, number of leaves, and SPAD values in dahlia and stock seedlings are presented in Figure 3. PBZ treatments were found to have statistically significant effects on stem diameter, number of leaves, and SPAD values in both types (P<0.001). Stem diameter values in dahlia seedlings differed between treatments. The highest stem diameter was determined in the 16 ppm PBZ treatment (4.24 mm), while the lowest value was determined in the 2 ppm PBZ treatment (3.30 mm). In stock seedlings, the highest stem diameter was obtained in the 4 ppm PBZ treatment (3.61 mm), while the lowest value was determined in the 16 ppm PBZ treatment (2.64 mm). The highest number of leaves in dahlia seedlings was determined in the 4 ppm PBZ treatment (30.00 leaves), while the lowest number of leaves was determined in the control treatment (17.17 leaves). In stock seedlings, the highest leaf count was obtained with the 16 ppm PBZ treatment (26.50 leaves), while the lowest value was determined with the 2 ppm PBZ treatment (22.70 leaves).

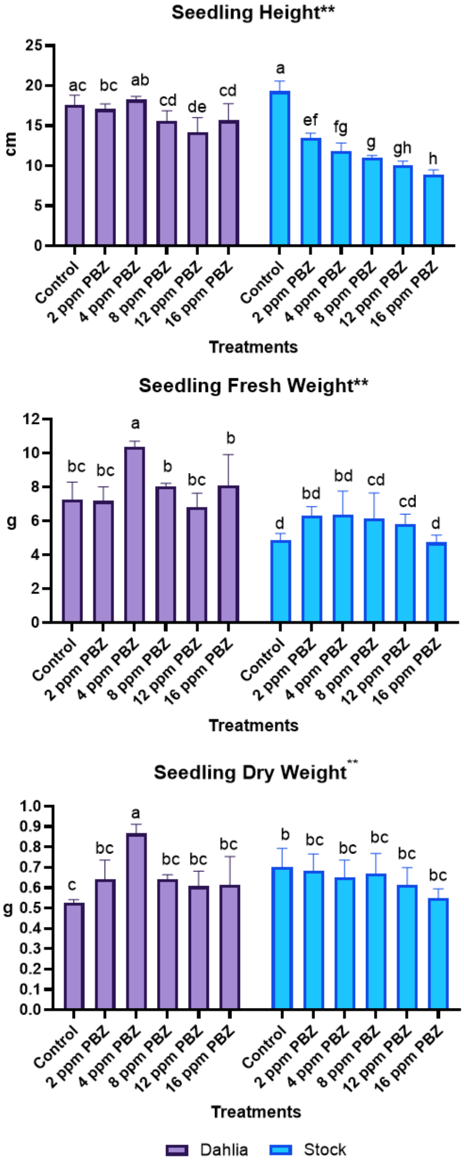

Figure 1. Effects of different paclobutrazol (PBZ) doses on seedling height, seedling fresh weight, and seedling dry weight in dahlia and stock seedlings. The columns represent means, and the bars represent standard errors of the three replicates, **= P<0.001.

The highest SPAD value in dahlia seedlings was measured in the 4 ppm PBZ treatment (44.37), while the lowest value was determined in the control treatment (36.53). In stock seedlings, the highest SPAD value was obtained with the 16 ppm PBZ treatment (59.65), while the lowest value was determined with the 2 ppm PBZ treatment (46.10).

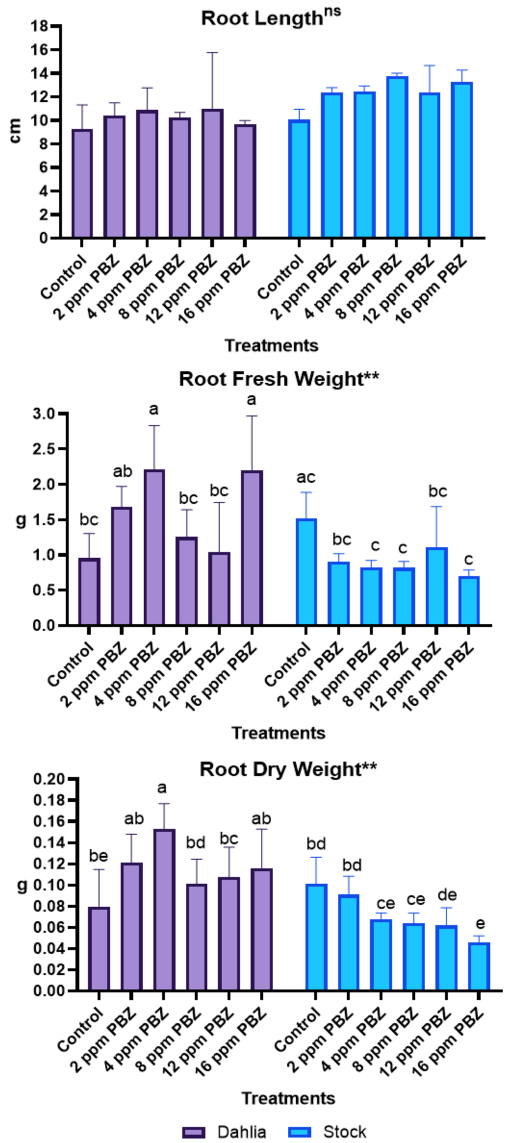

Figure 2. Effects of different paclobutrazol (PBZ) doses on root length, root fresh weight, and root dry weight in dahlia and stock seedlings. The columns represent means, and the bars represent standard errors of the three replicates, ns= non-significant, **= P<0.001.

4. Discussion

Paclobutrazol (PBZ) is one of the most widely used growth suppressants among triazole group plant growth regulators, and its primary effect is to inhibit gibberellin (GA) biosynthesis. It has been reported that PBZ inhibits the cytochrome P450-dependent ent-kaurene oxidase step in the GA biosynthesis pathway, preventing the oxidation of ent-kaurene to ent-kaurenoic acid; consequently, GA levels decrease, restricting cell elongation and internode elongation (Opio et al., 2020;

Desta and Amare, 2021; Nagar et al., 2021). This basic mechanism of action is directly consistent with our finding of a significant reduction in height (compaction) in both dahlia and stock seedlings treated with PBZ.

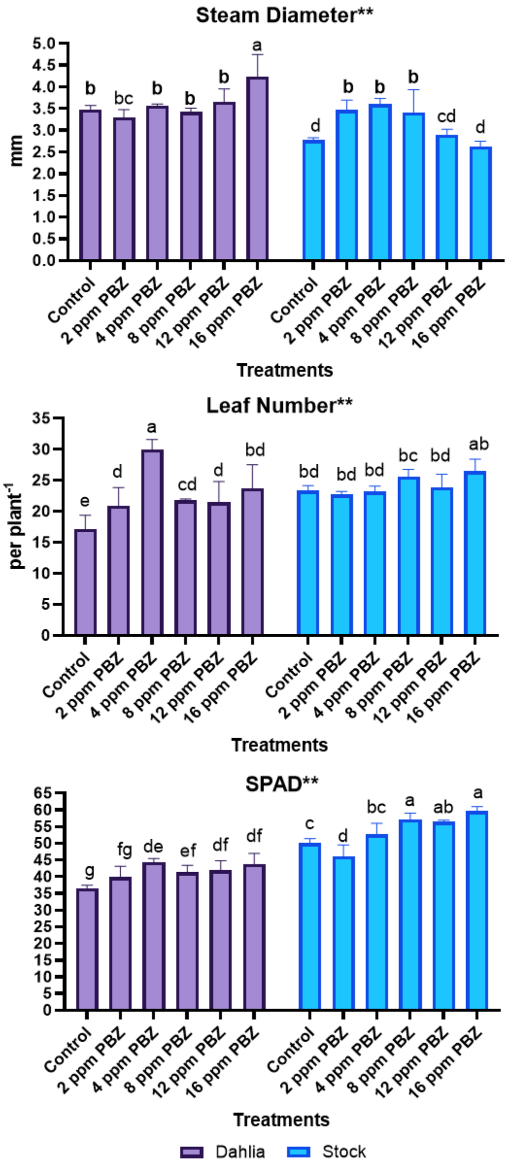

Figure 3. Effects of different paclobutrazol (PBZ) doses on stem diameter, leaf number, and SPAD values in dahlia and stock seedlings. The columns represent means, and the bars represent standard errors of the three replicates, *= P<0.05, **= P<0.001.

The effects of paclobutrazol (PBZ) treatments on seedling development and physiological characteristics largely overlap with growth-regulating effects frequently reported in ornamental plants (Ecker et al., 1992). The results obtained in this study indicate that PBZ induces significant changes in plant morphology and biomass distribution, depending on the dose. The morphological response in the plant due to the decrease in GA is not limited to "shortening"; PBZ causes stem thickening and the formation of a more "robust/compact" seedling structure in most species. Another notable outcome of PBZ treatments in this study is the increase in SPAD (chlorophyll index). Many studies have reported that PBZ darkens the green of leaves in most species, increasing chlorophyll content and/or chloroplast density, which is reflected in SPAD values (Liu et al., 2022; Wu et al., 2022; Hu et al., 2025). This situation can be explained by changes in leaf anatomy associated with GA reduction, PBZ's ability to protect photosynthetic structure and slow aging, and increased chlorophyll stability through the regulation of stress hormones and antioxidant systems (Desta and Amare, 2021; Liu et al., 2022; Wu et al., 2022). In stock and dahlia studies, the increase in SPAD at higher doses supports the effect of PBZ on "compact but darker green" seedling quality.

The effect of PBZ on root parameters varies in the literature depending on the species, dose, and treatment method. Under some conditions, PBZ can alter the plant's carbon distribution and support root development (especially root length/exploration capacity) by suppressing shoot growth more strongly; under other conditions, a decrease in root biomass (fresh/dry weight) may be observed (Desta and Amare, 2021; Hütsch et al., 2023; Fan et al., 2025). In dahlia and stock, the decrease in root fresh and dry weight despite the increase in root length may indicate a shift in root growth pattern under PBZ treatment. This pattern could be associated with the development of more elongated roots with relatively lower biomass. This situation can be attributed to the growth-suppressive effect of PBZ, which alters the root structure and redistributes resources to different organs (Opio et al., 2020).

Previous studies have reported that PBZ may be associated with increased abiotic stress tolerance under certain experimental conditions through its effects on hormonal balance, antioxidant defense, and osmotic regulation (Desta and Amare, 2021; Liu et al., 2022; Fan et al., 2025). However, as the primary objective of this study was to evaluate PBZ's effects on growth regulation and seedling architecture, these potential stress-related effects were not directly assessed and should be interpreted solely as contextual information derived from the literature. Although stress tolerance and post-transplant performance were not directly assessed in this study, the observed increases in SPAD values and the development of compact, robust seedlings suggest that PBZ treatments may indicate an improved physiological status during early growth stages. Future studies evaluating flowering behavior, time to market, and post-transplant growth dynamics will be essential to fully elucidate the long-term implications of PBZ use in dahlia and stock production systems.

5. Conclusion

This study demonstrated the effects of paclobutrazol (PBZ) treatments on seedling growth, biomass distribution, and physiological characteristics in dahlia and stock seedlings. The results clearly indicate that PBZ dose plays a decisive role in regulating growth parameters and that seedling responses vary between species. Overall, low to moderate PBZ doses, particularly 4 ppm, resulted in favorable outcomes for several growth and quality parameters, including seedling height, leaf number, fresh and dry weight, and SPAD values, especially in dahlia seedlings. The response to PBZ differed between species; PBZ was more effective in reducing seedling height (promoting compact growth) in stock seedlings compared to dahlia. Although higher PBZ doses increased stem diameter, they were associated with reductions or limitations in certain growth and biomass-related parameters. Therefore, optimization of PBZ dosage is critical for achieving compact, high quality seedlings. Given that PBZ is a growth regulator whose effects are highly dependent on species and dose, the optimal treatment rate should be determined in accordance with the target of "compactness and seedling quality." Excessive PBZ doses should be avoided, as they may unnecessarily suppress root biomass accumulation and overall plant growth.

Author Contributions

The percentages of the author' contributions are presented below. The author reviewed and approved the final version of the manuscript.

	O.S.A.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100
PM	100
FA	100

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The author declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

References

Agehara, S., & Leskovar, D. I. (2014). Growth reductions by exogenous abscisic acid limit the benefit of height control in diploid and triploid watermelon transplants. *HortScience, 49*(4), 465-471. https://doi.org/10.21273/HORTSCI.49.4.465

Agehara, S., & Leskovar, D. I. (2017). Growth suppression by exogenous abscisic acid and uniconazole for prolonged marketability of tomato transplants in commercial conditions. *HortScience, 52*(4), 606-611. https://doi.org/10.21273/HORTSCI11518-16

Baninasab, B., & Ghobadi, C. (2011). Influence of paclobutrazol and treatment methods on high-temperature stress injury in cucumber seedlings. *Journal of Plant Growth Regulation, 30*(2), 213–219. https://doi.org/10.1007/s00344-010-9188-2

Barrett, J. E. (2001). Mechanisms of action. In Tips on Regulating Growth of Floriculture Crops (pp. 32–41). OFA.

Desta, B., & Amare, G. (2021). Paclobutrazol as a plant growth regulator. *Chemical and Biological Technologies in Agriculture, 8*(1), 1. https://doi.org/10.1186/s40538-020-00199-z

Ecker, R., Barzilay, A., Afgin, L., & Watad, A. E. A. (1992). Growth and flowering responses of Matthiola incana LR BR. to paclobutrazol. *HortScience, 27*(12), 1330.

Eid, A. R., Awad, M. N., & Hamouda, H. A. (2009). Evaluate effectiveness of bio and mineral fertilization on the growth parameters and marketable cut flowers of Matthiola incana L. *American-Eurasian Journal of Agricultural and Environmental Science, 5*(4), 509-518.

Esmaielpour, B., Hokmalipour, S., Jalilvand, P., & Salimi, G. (2011). The investigation of paclobutrazol effects on growth and yield of two potato (Solanum tuberosum L.) cultivars under different plant density. *Journal of Food, Agriculture and Environment, 9*(3), 289–294.

Fan, S., Sun, X., Liang, G., Ma, Z., Hao, J., Wu, J., & Zhao, Y. (2025). Paclobutrazol enhances tall fescue salt tolerance via physiological and root system architecture modulation. *BMC Plant Biology, 25*(1), 1612. https://doi.org/10.1186/s12870-025-07616-1

Garner, L. C., & Björkman, T. (1999). Mechanical conditioning of tomato seedlings improves transplant quality without deleterious effects on field performance. *HortScience, 34*(5), 848-851.

Ghosh, A., Chikara, J., Chaudhary, D. R., Prakash, A. R., Boricha, G., & Zala, A. (2010). Paclobutrazol arrests vegetative growth and unveils unexpressed yield potential of Jatropha curcas. *Journal of Plant Growth Regulation, 29*(3), 307–315. https://doi.org/10.1007/s00344-010-9137-0

Hajihashemi, S., & Ehsanpour, A. A. (2013). Influence of exogenously applied paclobutrazol on some physiological traits and growth of Stevia rebaudiana Bertoni under in vitro drought stress. *Biologia, 68*(3), 414–420. https://doi.org/10.2478/s11756-013-0165-7

Hajihashemi, S., & Ehsanpour, A. A. (2014). Antioxidant response of Stevia rebaudiana Bertoni to polyethylene glycol and paclobutrazol treatments under in vitro culture. *Applied Biochemistry and Biotechnology, 172*(8), 4038–4052. https://doi.org/10.1007/s12010-014-0791-8

Hu, F., Lu, J., Zhai, L., Qiu, X., Du, B., & Xu, J. (2025). Effects of foliar treatment of paclobutrazol on grain yield, aroma, and canopy radiation use efficiency of aromatic rice. *Biology, 14*(11), 1562. https://doi.org/10.3390/biology14111562

Hütsch, B. W., Kehm, L., & Schubert, S. (2023). Does the plant growth regulator paclobutrazol enhance root growth of maize exposed to drought stress during flowering?. *Journal of Agronomy and Crop Science, 209*(5), 673–688. https://doi.org/10.1111/jac.12646

Irani, S. F., & Arab, M. (2017). Meiotic behavior and morpho-phenological variation in cut stock (Matthiola incana L.) flower. *Folia Horticulturae, 29*(1), 51–61. https://doi.org/10.1515/fhort-2017-0006

Jafari, S., Garmdareh, S. E. H., & Azadegan, B. (2019). Effects of drought stress on morphological, physiological, and biochemical characteristics of stock plant (Matthiola incana L.). *Scientia Horticulturae, 253*, 128-133. https://doi.org/10.1016/j.scienta.2019.04.033

Koutroubas, S. D., & Damalas, C. A. (2015). Sunflower response to repeated foliar treatments of paclobutrazol. *Planta Daninha, 33*, 129–135.

Latimer, J. G. (1998). Mechanical conditioning to control height. *HortTechnology, 8*(4), 529-534.

Liu, B., Long, S., Liu, K., Zhu, T., Gong, J., Gao, S., & Xu, Y. (2022). Paclobutrazol ameliorates low-light-induced damage by improving photosynthesis, antioxidant defense system, and regulating hormone levels in tall fescue. *International Journal of Molecular Sciences, 23*(17), 9966. https://doi.org/10.3390/ijms23179966

Markwell, J., Osterman, J. C., & Mitchell, J. L. (1995). Calibration of the Minolta SPAD-502 leaf chlorophyll meter. *Photosynthesis Research, 46*(3), 467-472.

Martínez-Damián, M. T., Cano-Hernández, R., Moreno-Pérez, E. D. C., Sánchez-del Castillo, F., & Cruz-Álvarez, O. (2019). Effect of preharvest growth bioregulators on physicochemical quality of saladette tomato. *Revista Chapingo. Serie Horticultura, 25*(1), 29–43. https://doi.org/10.5154/r.rchsh.2018.06.013

Million, J. B., Barrett, J. E., Nell, T. A., & Clark, D. G. (1999). Paclobutrazol distribution following treatment to two media as determined by bioassay. *HortScience, 34*(6), 1099–1102.

Misra, A., Srivastava, N. K., Kumar, R., & Khan, A. (2005). Effect of paclobutrazol (PP333) on flower quality and quantity of Rosa damascena Mill. *Communications in Soil Science and Plant Analysis, 36*(4–6), 477–486. https://doi.org/10.1081/CSS-200043219

Mukadam, S. J., & Haldankar, P. M. (2013). Effect of paclobutrazol and post flowering foliar sprays of nutrients for accelerating harvesting of karonda (Carissa carandas L.). *Journal of Plant Studies, 2*(1), 145.

Nagar, S., Singh, V. P., Arora, A., Dhakar, R., Singh, N., Singh, G. P., & Ramakrishnan, R. S. (2021). Understanding the role of gibberellic acid and paclobutrazol in terminal heat stress tolerance in wheat. *Frontiers in Plant Science, 12*, 692252. https://doi.org/10.3389/fpls.2021.692252

Opio, P., Tomiyama, H., Saito, T., Ohkawa, K., Ohara, H., & Kondo, S. (2020). Paclobutrazol elevates auxin and abscisic acid, reduces gibberellins and zeatin and modulates their transporter genes in Marubakaido apple rootstocks. *Plant Physiology and Biochemistry, 155*, 502–511. https://doi.org/10.1016/j.plaphy.2020.08.003

Orozco-Meléndez, L. R., Hernández-Rodríguez, O. A., Cruz-Álvarez, O., Robles-Hernández, L., Ávila-Quezada, G. D., Chavez, E. S., & Ojeda-Barrios, D. L. (2022). Paclobutrazol and its use in fruit production: A review. *Phyton, 91*(1), 1. https://doi.org/10.32604/phyton.2022.016908

Sánchez, J. L., Domina, G., & Caujapé-Castells, J. (2005). Genetic differentiation of three species of Matthiola (Brassicaceae) in the Sicilian insular system. *Plant Systematics and Evolution, 253*(1), 81–93.10. https://doi.org/10.1007/s00606-005-0307-7

Schneck, K. K., Boyer, C. R., & Miller, C. T. (2021). Supraoptimal Root-zone temperatures affect dahlia growth and development. *HortTechnology, 31*(6), 667-678. https://doi.org/10.21273/HORTTECH04896-21

Sponsel, V. M. (1995). *The biosynthesis and metabolism of gibberellins in higher plants*. In P. J. Davies (Ed.), *Plant hormones: Physiology, biochemistry and molecular biology* (pp. 66–97). Springer.

Srivastav, M., Kishor, A., Dahuja, A., & Sharma, R. R. (2010). Effect of paclobutrazol and salinity on ion leakage, proline content and activities of antioxidant enzymes in mango (Mangifera indica L.). *Scientia Horticulturae, 125*(4), 785-788. https://doi.org/10.1016/j.scienta.2010.05.023

Sun, Y. W., Chen, J. J., Chang, W. N., Tseng, M. J., & Wu, F. S. (2010). Irrigation with 5 °C water and paclobutrazol promotes strong seedling growth in tomato (Solanum lycopersicum L.). *The Journal of Horticultural Science and Biotechnology, 85*(4), 305–311. https://doi.org/10.1080/14620316.2010.11512672

Telewski, F. W. (2016). Thigmomorphogenesis: The response of plants to mechanical perturbation. *Italus Hortus, 23*(1), 1-16.

Uddling, J., Gelang-Alfredsson, J., Piikki, K., & Pleijel, H. (2007). Evaluating the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings. *Photosynthesis Research, 91*(1), 37-46.

Wu, Y., Liu, J., Zhao, D., & Tao, J. (2022). Effect of paclobutrazol treatment on plant growth and flower quality in herbaceous peony. *Phyton, 91*(9), 2017. https://doi.org/10.32604/phyton.2022.020643

Xu, G., Luo, R., & Yao, Y. (2013). Paclobutrazol improved the reproductive growth and the quality of seed oil of Jatropha curcas L. *Journal of Plant Growth Regulation, 32*(4), 875–883. https://doi.org/10.1007/s00344-013-9353-5

Zheng, R. R., Wu, Y., & Xia, Y. P. (2012). Chlorocholine chloride and paclobutrazol treatments promote carbohydrate accumulation in bulbs of Lilium Oriental hybrids 'Sorbonne'. *Journal of Zhejiang University Science B, 13*(2), 136–144. https://doi.org/10.1631/jzus.B1000425

Zhou, X., Zhang, Y., Leng, S., Wang, Z., Gong, C., Zuo, Q., & Yang, G. (2022). Uniconazole and adaptability of transplantations by enhancing the competition tolerance in a high sowing density of rapeseed blanket seedlings. *Agronomy, 12*(11), 2637. https://doi.org/10.3390/agronomy12112637

Zhou, Z., Ma, H., Liang, K., Huang, G., & Pinyopusarerk, K. (2012). Improved tolerance of teak (Tectona grandis L. f.) seedlings to low-temperature stress by the combined effect of arbuscular mycorrhiza and paclobutrazol. *Journal of Plant Growth Regulation, 31*(3), 427–435. https://doi.org/10.1007/s00344-011-9252-6