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Modulating bolting and flowering in lettuce: synergistic effects of paclobutrazol, growing systems, and application methods

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ABSTRACT

Premature bolting limits the yield and quality of lettuce (*Lactuca sativa* L.). This study assessed the effects of paclobutrazol (PBZ) application (50 ppm), growing systems (soil-based and hydroponic), and modes of application (seed priming, root dip, foliar spray) on bolting and flowering timing. Conducted during 2023–2024 at SKUAST-K, the experiment followed a factorial randomized complete block design. PBZ-treated plants showed delayed flower initiation (89.4 days), bolting (95.6 days), and anthesis (102.3 days) compared to controls (85.6, 92.6, and 98.9 days, respectively). Hydroponic-grown lettuce delayed flowering (88.35 days) compared to soil-grown (86.65 days). Foliar application delayed flowering (92.7 days), bolting (101.8 days), and anthesis (109.9 days) more effectively than seed priming or root dip. The combined treatment of PBZ with hydroponics and foliar spray (P2×S1×M3) achieved the most delayed flower initiation (94.9 days), bolting (103.2 days), and anthesis (111.2 days). Delays in bolting and flowering were statistically significant (C.D. at p≤0.05: 0.27–0.36 days). These results demonstrate that PBZ, especially via foliar application in hydroponics, can substantially extend the vegetative phase, improving stress tolerance and market quality in lettuce.

Key words: Bolting delay, hydroponics, lettuce and paclobutrazol

Lettuce (*Lactuca sativa* L.) is a globally important leafy vegetable, valued for its nutrition, rapid growth, and economic significance. However, premature bolting and flowering, triggered by high temperatures, long photoperiods, and water stress, severely reduce its quality and yield (Seginer *et al*., 1991; Ryder, 1999). Early bolting leads to tougher, bitter leaves and shortens the harvest window. Plant growth regulators (PGRs), particularly paclobutrazol (PBZ), have been explored to delay flowering and modulate plant growth. PBZ, a triazole compound, inhibits gibberellin biosynthesis, restricts vegetative growth, enhances stress tolerance, and improves yield potential (Rademacher, 2000; Arteca, 2013; Fletcher *et al*., 2000). However, studies specifically addressing PBZ's effects on lettuce bolting are limited. Growing systems also influence plant responses to PGRs. Hydroponic systems enable precise delivery of nutrients and chemicals, potentially enhancing PBZ efficacy (Resh, 2022; Gruda, 2009), while soil-based cultivation introduces variability affecting nutrient uptake. Additionally, the mode of PBZ application - foliar spray, root drench, or substrate incorporation - affects absorption and distribution (Gao *et al.*, 2018). Yet, the interactive effects of growing systems and application modes on PBZ efficacy in lettuce remain underexplored. Thus, this study was undertaken to investigate the individual and combined effects of paclobutrazol, cultivation systems (soil and soilless), and application methods on flower initiation, bolting, and anthesis in lettuce. The findings aim to optimize bolting management practices to enhance quality and extend the vegetative phase under diverse production environments.

MATERIALS AND METHODS

The experiment was conducted during 2023–2024 at the Division of Basic Sciences and Humanities, SKUAST-K, Shalimar, Srinagar (Jammu and Kashmir, India), situated at 1600 m above mean sea level with an average annual rainfall of 645 mm. The region experiences cool springs and autumns, mild summers, and cold winters. Surface sterilized seeds of L-S-2 lettuce (1% NaOCl for 1 minute) were sown in pre-soaked Oasis foam cubes and maintained at 22 ± 2°C with 70 - 80% RH). Seedlings of 2–3 true leaves and along with Oasis cube were transferred into netted cups containing a 1:1:1 mix of cocopeat, vermiculite, and perlite. These cups were placed in a three-layered nutrient film technique (NFT) system and a commercial hydroponic nutrient solution was maintained at EC 1.5–1.8 mS cm^{-1} and pH 5.8–6.2, circulated at 1–2 L min^{-1} and replenished weekly. For soil-based cultivation, seedlings were transplanted into the field with 25 cm × 25 cm spacing. All the experimentation was done under open environmental conditions. Application of paclobutrazol @50 ppm was done as seed priming (M1), root dip (M2) and foliar spray (M3). Time to flower initiation, bolting, and anthesis was recorded at two-day intervals as the number of days from transplanting to: (i) Visible flower bud formation at the apical meristem, (ii) Stem elongation >5 cm indicating bolting, and (iii) First flower opening with visible reproductive parts (Zhang *et al.*, 2018). The experiment followed a factorial randomized complete block design (FRBD) with three replications. Data were analyzed using analysis of variance (ANOVA), and treatment means were separated using critical difference (C.D.) at a 5% level of significance (Gomez and Gomez, 1984). Statistical analysis was performed using SPSS version 22.0 and Microsoft Excel.

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RESULTS AND DISCUSSION

Paclobutrazol (PBZ) application at 50 ppm significantly delayed flowering and bolting in lettuce compared to the control. PBZ-treated plants flowered at 89.4 days, bolted at 95.6 days, and reached anthesis at 102.3 days, while control plants did so earlier at 85.6, 92.6, and 98.9 days, respectively (C.D. at $p \leq 0.05$: 0.29, 0.19, and 0.36 days). The delay is attributed to PBZ's inhibition of gibberellin biosynthesis and enhancement of antioxidative defenses (Fukazawa *et al.*, 2022; Zhou *et al.*, 2022a), consistent with findings by Park *et al.* (2023). Hydroponic cultivation (S1) further delayed reproductive development compared to soil-based cultivation (S2). Flowering, bolting, and anthesis occurred at 88.35, 95.1, and 102.6 days under hydroponics, versus 86.65, 93.1, and 98.6 days in soil ($p \leq 0.05$). This delay is attributed to stable nutrient supply, reduced abiotic stress, and improved root zone conditions in hydroponics (Savvas and Gruda, 2023a; He *et al.*, 2023; Rahman *et al.*, 2022). The mode of PBZ application also had a significant effect. Foliar spray (M3) was most effective, with flowering at 92.7 days, bolting at 101.8 days, and anthesis at 109.9 days, compared to seed priming (M1: 87.8, 93.4, and 99.8 days) and root dip (M2: 84.6, 90.2, and 98.2 days). The superior efficacy of foliar spray is attributed to rapid PBZ absorption and direct modulation of gibberellin pathways, along with enhanced antioxidative defenses (Wang *et al.*, 2023a; Sharma and Singh, 2022; Zhou *et al.*, 2022b). Significant first-order interactions of PBZ concentration, growing system, and application mode influenced bolting and flowering in lettuce. In PBZ × growing system (P×S) interactions, 50 ppm PBZ in hydroponics (P2×S1) delayed flowering (90.1 days), bolting (96.6 days), and anthesis (103.2 days), while untreated soil-grown plants (P1×S2) transitioned earliest. For PBZ × application mode (P×M), foliar spray with 50 ppm PBZ (P2×M3) showed maximum delay (95.6, 102.4, and 110.4 days), whereas untreated root dip plants (P1×M2) flowered earliest.

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Table: 1. Effect of PBZ and growing system on bolting and flowering of lettuce

Treatment	Time taken to flower initiation (Day)	Time taken to bolting (Day)	Time taken to flower anthesis (Day)
Individual effects of PBZ (P)			
P1	85.6	92.6	98.9
P2	89.4	95.6	102.3
C.D. $(p\leq 0.05)$	0.29	0.19	0.36
Individual effects of growing system (S)			
S1	88.35	95.1	102.6
S2	86.65	93.1	98.6
C.D. $(p\leq 0.05)$	0.29	0.19	0.36
Individual effects of mode of application (M)			
M1	87.8	93.4	99.8
M2	84.6	90.2	98.2
M3	92.7	101.8	109.9
C.D. $(p\leq 0.05)$	0,29	0.19	0.36
1st order interaction			
$P_1\times S_1$	86.6	93.6	102.0
$P_1\times S2$	84.5	91.6	95.7
$P2\times S_1$	90.1	96.6	103.2
$P2\times S_2$	88.8	94.6	101.5
$P_1\times M_1$	85.2	91.55	95.3
$P_1\times M_2$	80.2	87.15	95.05
$P_1\times M_3$	89.5	99.05	106.3
$P_2\times M_1$	87.2	92.8	98.45
$P_2\times M_2$	85.6	91.8	98.15
$P_2\times M_3$	956	102.4	110.4
$S_1\times M_1$	87.8	93.4	99.8
$S_1\times M_2$	84.6	90.2	98.2
$S_1\times M_3$	92.7	101.8	109.9
$S_2\times M_1$	84.6	91.0	94.0
$S_2\times M_2$	83,0	88.7	95.1
$S_2\times M_3$	92.4	99.7	106.9
C.D. $(p\leq 0.05)$	0,31	0.21	0.33
2nd order interaction			
$P_1\times S_1\times M_1$	86.8	92.6	100.1
$P_1\times S_1\times M_2$	82.5	87.8	97.5
$P_1\times S_1\times M_3$	90.5	100.3	108.5
$P_1\times S_2\times M_1$	83.6	90.5	90.5
$P_1\times S_2\times M_2$	81.5	86.5	92.6
$P_1\times S_2\times M_3$	88.5	97.8	104.1
$P_2\times S_1\times M_1$	88.8	94.2	99.5
$P_2\times S_1\times M_2$	86.6	92.5	98.8
$P_2\times S_1\times M_3$	94.9	103.2	111.2
$P_2\times S_2\times M_1$	85.6	91.4	97.4
$P_2\times S_2\times M_2$	84.5	90.8	97.5
$P_2\times S_2\times M_3$	96.2	101.5	109.6
C.D. $(p\leq 0.05)$	0.27	0.19	0.34

In growing system × application mode (S×M), foliar spray in hydroponics (S1×M3) delayed development most, while soil root dip (S2×M2) was fastest. All differences were significant (p≤0.05). These results highlight that PBZ, especially through foliar spray in hydroponics, delays bolting by enhancing absorption, optimizing nutrients, inhibiting gibberellin biosynthesis, and boosting Protective antioxidant responses (Wang *et al.*, 2023b; Savvas and Gruda, 2023b; Sharma and Singh, 2022; Zhou *et al.*, 2022c). The 2nd order interactions between paclobutrazol (PBZ), growing systems, and modes of application significantly influenced bolting and flowering in lettuce. The combination of 50 ppm PBZ (P2) with hydroponics (S1) and foliar spray (M3) (P2×S1×M3) resulted in delayed flower initiation (94.9 days), bolting (103.2 days), and anthesis (111.2 days). In contrast, untreated lettuce with root dip application in soil (P1×S2×M2) flowered earliest (81.5 days), bolted at 86.5 days, and reached anthesis at 92.6 days. The critical difference (C.D.) at p≤0.05 was 0.27, 0.19, and 0.34 days for flower initiation, bolting, and anthesis, respectively. The delayed bolting and flowering in PBZ treatments, especially in hydroponics and foliar spray, can be attributed to better PBZ absorption, which inhibits gibberellin biosynthesis and promotes the vegetative phase (Wang *et al.*, 2023a; Savvas and Gruda, 2023c). Additionally, PBZ's enhancement of stress resilience and antioxidative defenses may have extended the vegetative period (Zhou *et al*., 2022c).

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CONCLUSION

Paclobutrazol (PBZ) application, especially via foliar spray in hydroponic systems, significantly delayed bolting and flowering in lettuce by inhibiting gibberellin biosynthesis and activating the plant's free radical scavenging capacity. Foliar application of PBZ in a hydroponic system exhibited a synergistic effect by prolonging the vegetative phase and enhancing the plant's stress tolerance, emphasizing PBZ's role in improving lettuce growth and yield performance.

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CONFLIT OF INTEREST

All the authors affirm that there is no conflict of interest among them. All research activities comply with relevant legal, institutional and ethical standards.

AUTHOR CONTRIBUTION

All the authors contributed equally in the present study.

REFERENCES

Arteca, R.N. 2013. *Plant Growth Substances: Principles and Applications* (eBook ed.). Springer Science & Business Media.

Fletcher, R.A., Gilley, A., Sankhla, N. and Davis, T. D. 1999. Triazoles as plant growth regulators and stress protectants. *Horticultural Reviews*, **24:** 55-138. John Wiley & Sons.

Fukazawa, J., Ohashi-Ito, K. and Ito, T. 2022. "Regulatory roles of gibberellins in plant development." *Journal of Plant Research*, **135**: 1-14.

Gao, L., Sun, X., Chang, L. and Chen, Y. 2018. Effects of paclobutrazol on growth and physiological characteristics in different crops: A review. *Plant Growth Regulation*, **86:** 17-28.

Gomez, K.A. and Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research* (2nd ed.). New York: John Wiley & Sons.

Gruda, N. 2009. Do soilless culture systems have an influence on product quality of vegetables? *Journal of Applied Botany and Food Quality*, **82**: 141-147.

He, L., Chen, X. and Zhao, Y. 2023. "Comparative analysis of bolting behavior in lettuce under hydroponic and soil cultivation systems." *Scientia Horticulturae*, 321: 112300.

Park, J., Kim, M. and Lee, H. 2023. Paclobutrazol application delays bolting and enhances marketability in lettuce under varied environmental conditions. *Scientia Horticulturae*, **320**: 112274.

Rademacher, W. 2000. Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. *Annual Review of Plant Biology*, 51: 501-531.

Rahman, M.M., Akond, A.S.M. and Islam, M.S. 2022. Growth and reproductive responses of lettuce under different cultivation systems: A physiological perspective. *Plants*, **11**: 3244.

Resh, H.M. 2022. *Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower* (7th ed.). CRC Press.

Ryder, E.J. 1999. *Lettuce, Endive, and Chicory*. CABI Publishing.

Savvas, D. and Gruda, N. 2023a. Application of soilless culture technologies in the modern greenhouse industry-A review. *European Journal of Horticultural Science*, **88**: 3-22.

Savvas, D. and Gruda, N. 2023b. Application of hydroponics for sustainable vegetable production in the era of climate change. *Horticulturae*, **9**: 207.

Savvas, D. and Gruda, N. 2023c. Hydroponics and its role in controlled environment agriculture for enhanced plant growth and productivity. *Horticultural Science*, **58**: 77-90.

Seginer, I., Marom, T. and Feller, U. 1991. Modeling lettuce development in relation to temperature and light: Comparison of experimental data and model simulation. *Scientia Horticulturae*, **45**: 275-289.

Sharma, R., & Singh, D. 2022. Effect of paclobutrazol application methods on growth, flowering, and antioxidative responses in horticultural crops: A review. *International Journal of Plant Physiology and Biochemistry*, **14**: 10-19.

Wang, L., Zhang, Y., Li, Q. and Chen, F. 2023a. Foliar application of paclobutrazol regulates gibberellin pathways and delays flowering in leafy vegetables. *Plant Growth Regulation*, **100**: 321-330.

Wang, Y., Zhang, X. and Li, H. 2023. Effects of paclobutrazol application on growth, flowering, and antioxidant capacity of hydroponically grown lettuce. *Journal of Plant Growth Regulation*, **42**: 105-115.

Zhang, Y., Yu, H., Yang, X., Li, Q., Ling, Y. and Liu, X. 2018. Inflorescence development and the role of LsFT in regulating bolting in lettuce (*Lactuca sativa* L.). *Frontiers in Plant Science*, **9**: 1094.

Zhou, J., Liu, Y. and Wang, Y. 2022c. The impact of paclobutrazol on plant stress tolerance and antioxidative defenses in lettuce. *Plant Physiology and Biochemistry*, **174**: 140-149.

Zhou, X., Wu, Z., Liu, Y. and Han, Z. 2022b. Paclobutrazol-mediated enhancement of antioxidant capacity delays bolting and senescence in lettuce. *Scientia Horticulturae*, **303**: 111236.

Zhou, Y., Li, Z. and Wang, R. 2022a. Paclobutrazol improves stress tolerance and modulates flowering in leafy vegetables. *Plant Physiology and Biochemistry*, **185**: 55-64.

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