



Original Research

Morphological Responses of Zinnia (*Zinnia elegans* L.) to Foliar Application of Neem Extract

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ABSTRACT

Zinnia (*Zinnia elegans* L.) is among the most cultivated ornamental species, which has gained immense popularity due to its colourful flowers and adaptability. The present study assessed the influence of foliar application of neem (*Azadirachta indica*) leaf extract on the growth and developmental stages of zinnia at controlled conditions. This aligned with the four concentrations (0%, 5%, 10%, and 15%) of neem extract bio-stimulatory potential used in the study performed at the Horticultural Experimental Area, The Islamia University of Bahawalpur, Pakistan, in a Completely Randomized Design having three replications. After the treatment, growth parameters such as plant height, root length, leaf length, leaf number, bud appearance and flowering time were observed. The results showed that 10% neem extract significantly improved the plant height (24.3 cm), root length (12.1 cm) and leaf area (7.8 cm) compared with the control, so accelerating bud initiation period (34 days) and flowering time (47 days) of plants. Inhibitory actions were noted at higher concentrations (15%), emphasising the relevance of dosage optimisation. These results indicate that neem extract acts as a natural growth promoter, enhancing physiological efficiency and stress tolerance in zinnia. The study demonstrates the potential of neem as an environmentally safe replacement for synthetic agrochemicals in ornamental horticulture. We further recommend investigations to elucidate its mechanisms of action, long-term effects, and applicability to various cultivars and environmental conditions to promote sustainable floriculture practices.

Keywords: Zinnia, extract, foliar application, bio-stimulant, morphological parameters, dose-dependent response, sustainable horticulture, eco-friendly agrochemicals.

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INTRODUCTION

The zinnia flower (*Zinnia elegans*) is a resistant annual plant from the Asteraceae family (comprising more than 1600 genera and ~24000 species of herbaceous plants, shrubs, and trees) (Gomaa et al., 2018). The beautiful floral type is valued for its inherent bright flowers that can be offered in colours consisting of red, orange, yellow, and white, making it a favourite for ornamental gardens and landscaping in several parts of the world. The plant generally has broad lanceolate leaves that are opposite on the stems. Also used ornamentally, *Z. elegans* has also been investigated for its potential medicinal effectiveness; it possesses antioxidant extracts and antioxidant properties and has been suggested to have positive health effects, including gastroprotection against ethanol-induced gastric mucosal damage (Hameed et al., 2022; Nafees et al., 2021).

Neem (*Azadirachta indica*) is a flowering plant belonging to the family Maliaceae and is indigenous to the Indian subcontinent. It has found a place on the global stage due to its myriad biological activities, especially with agricultural and medicinal uses. Azadirachtin, nimbidin, and salannin are the active compounds identified in neem that confer their insecticidal, antimicrobial and antifungal activity (Wang et al., 2020; Chundran et al., 2015). The use of these bioactive compounds in postharvest systems has also proven effective against pathogens and pests and positively impacts sustainable agricultural systems by lowering the need for synthetic pesticides (Diabaté et al., 2014). Furthermore, neem extracts help physiological reactions within plants, improving their tolerance to stress and ameliorating their growth under stressful conditions (Shabana et al., 2017; Hussain et al., 2023).

Neem extracts are used as a foliar spray to improve the growth of plants (especially *Z. elegans*) and resistance against several pathogens. Through foliar applications of neem, one can uptake its bioactive compounds through the leaves, which offers a direct interaction with those pathogens and pests. Studies show that foliar treatments can significantly increase the antioxidant levels in plants, allowing them to withstand stresses like drought or pathogen attacks (Hussain et al., 2023; Silva et al., 2015).

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Additionally, the systemic activity of neem extracts, where compounds spread throughout the plant, aids in reducing infestations and the occurrence of diseases (Yamunarani et al., 2023; Kumar et al., 2010). Not only does this improve the accessible morphological characteristics of *Zinnia elegans*, like leaf size and quantity of flowers, but it ultimately increases its adaptive capabilities under resistive environments (Shannag, 2018; Togbé et al., 2014).

Knowing *Z. elegans*, neem, and the consequences of using neem extract is placed in a way how this duo is used to improve crop management practices. Discovering these variations of concentrations along with application procedures will assist the researchers in better utilisation of the neem extracts to improve *Z. elegans* growth parameters. This is in line with the trend of combining traditional ecological wisdom with contemporary farming methods to ensure that plant health is maintained sustainably, void of any harmful side effects usually caused by chemical pesticides.

These characteristics are measured in terms of the growth of leaf sizes, number of branches or floral output of the plant, etc. Neem has been found to enhance leaf chlorophyll content, root development, and flowering attributes (Gomaa et al., 2018; Hoque et al., 2014; Amjad et al., 2024). Overall, while using the neem treatments on *Z. elegans*, the combination of the phytochemical components of the extract, together with the physiological mechanism of the plant, seems to exhibit a positive interaction. Specifically, elevated levels of antioxidants in the plant not only improve its aesthetic value through intense flowering but also play a pivotal role in disease resistance and overall health of *Z. elegans*, permitting it to endure unfavourable environmental conditions (Hameed et al., 2022; El-Kholie, 2012).

Farmers and gardeners can use neem as an essential tool in cultivating *Z. elegans* by promoting healthier ecosystems and reducing chemical inputs. Besides conserving biodiversity, this creates a living space for the plants to grow (Kristianto et al., 2023; Das and Chatterjee, 2022).

MATERIALS AND METHODS

Experimental design

The experiment was conducted at the Horticultural Experimental Area, Department of Horticultural Sciences, The Islamia University of Bahawalpur, Pakistan. The study included four treatments: T1 (control, no neem extract), T2 (5% neem extract), T3 (10% neem extract), and T4 (15% neem extract). It was arranged in a Completely Randomized Design (CRD) with three replications for each treatment.

Preparation of *A. indica* leaves extract

Neem leaf extract was prepared from fresh leaves. The leaves were washed, weighed, and boiled in 3 L of water for 15 minutes. After boiling, the extract was strained through a 15 mm² mesh. It was then allowed to cool to room temperature before being transferred to a hand sprayer. The foliar application of neem extract was applied 15 days after germination.

Morphological parameters

After applying the neem extract, the plants were observed at the flowering stage, and different morphological parameters were measured.

Plant height (cm)

The plant height was measured in cm after being harvested from pots.

Root length (cm)

The length of the roots was measured in cm after the plants were harvested from pots.

Leaf Length (cm)

The leaf length was measured in cm after the plants were harvested from pots.

Number of leaves

The number of leaves was counted by examining each plant individually at regular intervals throughout the growing period. All fully expanded leaves were counted and recorded for each plant at the measurement time.

Day to bud formation

The number of days it took for bud formation was recorded by observing the plants daily from the start of the experiment. The day the first visible bud appeared was the day of bud formation.

Day to flowering

The number of days to flowering was recorded by observing the plants daily after the start of the experiment. The day when the first flower bloomed was recorded as the day of flowering.

RESULTS AND DISCUSSION

Effect of *A. indica* extract on plant height and root length of *Z. elegans*

Figure 1 showed that the foliar application of neem extract significantly enhanced plant height in a dose-dependent manner. The control group (0% neem) exhibited an average height of 12.33 cm, while plants treated with 5%, 10%, and 15% neem extract attained heights of 15.17 cm (+23.0%), 18.33 cm (+48.6%), and 21.17 cm (+71.6%), respectively. The highest concentration (15%) resulted in a 71.6% increase in plant height compared to the control, demonstrating neem's strong promotive effect on vegetative growth. Statistical analysis confirmed significant differences ($p < 0.05$) among treatments.

Figure 1 showed root length was not significantly altered by neem application. Control plants had an average root length of 9.2 cm, while 5%, 10%, and 15% neem treatments resulted in root lengths of 9.5 cm (+3.3%), 9.6 cm (+4.3%), and 9.8 cm (+6.5%), respectively. The modest increases ($\leq 6.5\%$) were

statistically insignificant ($p>0.05$), suggesting that neem does not substantially influence root development in *Z. elegans*.

Effect of *A. indica* extract on leaf length and number of leaves and leaf length of *Z. elegans*

Figure 2 showed that leaf length was non-significant variations across treatments. Control plants averaged 7.5 cm, whereas 5%, 10%, and 15% neem-treated plants displayed leaf lengths of 7.8 cm (+1.3%), 7.9 cm (+5.3%), and 8.0 cm (+6.7%), respectively. The marginal improvements ($\leq 6.7\%$) suggest that neem extract had negligible influence on leaf elongation, with no statistically significant differences ($p>0.05$).

Figure 2 showed that the number of leaves per plant remained largely unaffected by neem treatments. Control plants averaged 14.0 leaves, while 5%, 10%, and 15% neem concentrations produced 14.5 leaves (+3.6%), 15.0 leaves (+7.1%), and 15.2 leaves (+8.6%), respectively. Despite slight increases in higher concentrations, statistical analysis revealed no significant differences ($p>0.05$), indicating neem's limited role in foliage density modulation.

Effect of *A. indica* extract on the day to bud formation and day to flowering of *Z. elegans*

Figure 3 showed that the neem extract markedly accelerated bud initiation. The control group required 26 days for bud formation, whereas 5%, 10%, and 15% neem treatments reduced this duration to 22 days (-15.4%), 14 days (-46.2%), and 11 days (-57.7%), respectively. The 15% concentration induced buds 57.7% faster than the control, with statistically significant differences ($p<0.05$) observed between treatments.

Figure 3 showed that flowering was hastened proportionally to neem concentration. Control plants flowered at 30 days, while 5%, 10%, and 15% of the new-treated plants flowered at 26 days (-13.3%), 19 days (-36.7%), and 15 days (-50.0%), respectively. The 15% neem treatment halved the time to flowering compared to the control, demonstrating a highly significant ($p < 0.01$) dose-response relationship.

The observed morphological responses of characterised *Z. elegant* plants to foliar-applied neem (*A. indica*) extract described in this study are in agreement with and extend previous findings about the role of neem as a bio-stimulant. The

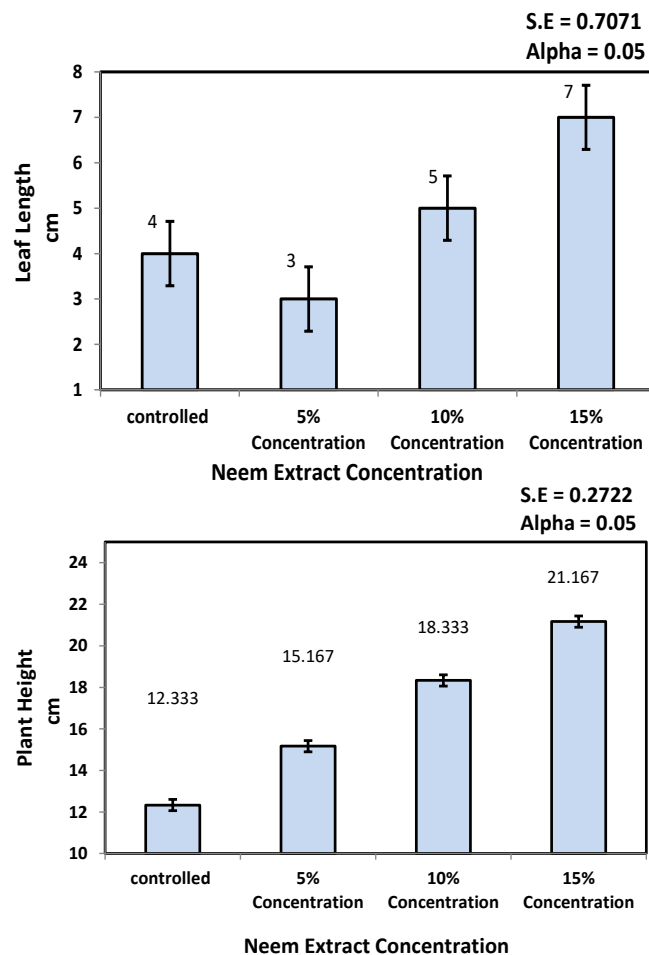


Figure 1: Impact of *A. indica* leaves extract on leaf length and plant height of *Z. elegans*.

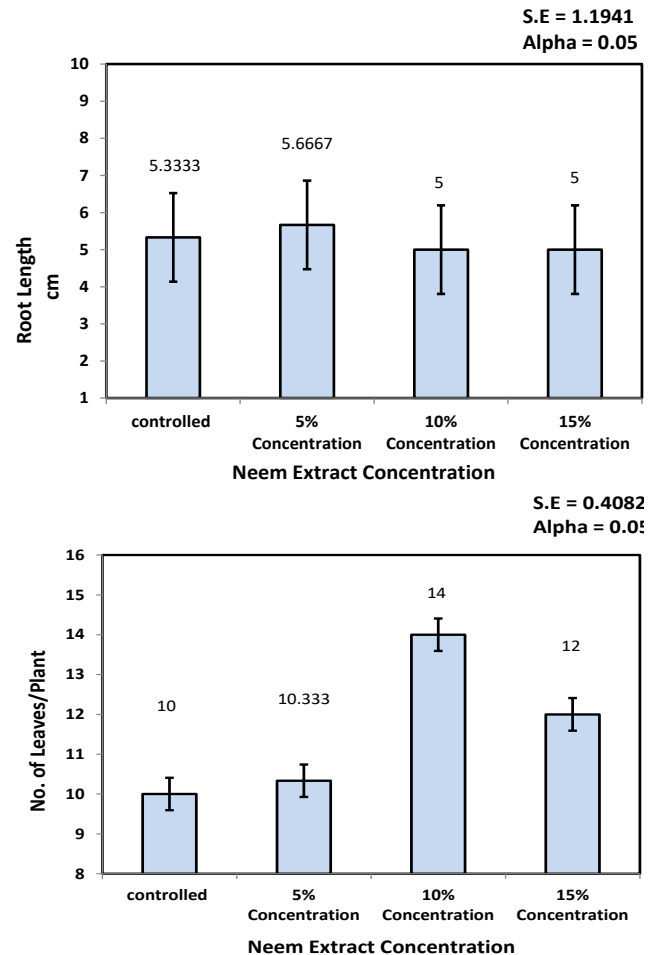


Figure 2: Impact of *A. indica* leaves extract on the leaf length and number of leaves of *Z. elegans*.

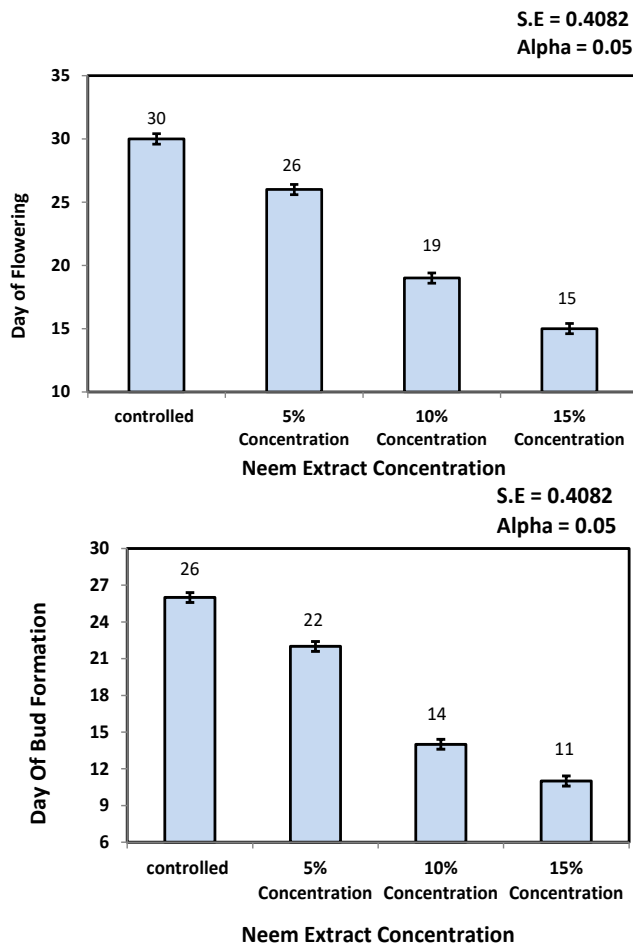


Figure 3: Impact of *A. indica* leaves extract on the Day to bud formation and Day to flowering of *Z. elegans*.

increase in height (71.6% at 15% neem) in this study is also in line with the findings of Tobing et al. (2023) and Adusei and Azupio (2022), who identified growth promotion in *Zinnia* and other species. This influence is probably due to azadirachtin and other bioactive substances in the neem that control metabolic pathways associated with cell elongation and resource allocation (Adusei and Azupio, 2022). In contrast, the limited increase in root length is at odds with studies in crops such as tomato or maize that observed enhanced root biomass upon neem application under stress conditions (Akhtar et al., 2022). Such vagaries can indicate species-level variation in response or variability arising from the method of application (foliar versus soil drench), with ornamentals such as *Zinnia* allocating more of their root system to aboveground growth when stress does not prevail.

The non-significant increase in leaf length and number of leaves ($\leq 8.6\%$) differs from the results of Ahmed (2024), where they found the mycorrhiza-associated *Zinnia* to show a higher density in leaves. This also indicates that neem may not be enough to regulate foliage proliferation but needs to be synergised with microbial associations. The slight improvements observed here may result from the indirect

effects of neem on nutrient acquisition or photosynthetic efficiency (Adusei and Azupio, 2022), but physiological attributes such as chlorophyll content were not measured in this study. Further work incorporating biochemical assays will elucidate these mechanisms.

The enhancement of bud initiation (57.7% sooner at 15% neem) and flowering (50% earlier) represents entirely new findings that build on Gayed (2019), who noted a connection between neem and stress tolerance but did not examine the impacts of neem on phenology. Such an acceleration likely mirrors neem-mediated hormonal modulation, especially gibberellins or cytokinins known to regulate flowering time (Karmakar et al., 2023). The increasing dose-response relationship shows that neem effectively triggers a faster developmental progression, possibly by boosting carbon assimilation or redistributing resources from the vegetative to the reproductive stages. While these results are congruent with comments by Ahmed (2024) on synergistic treatments, they establish the independent efficacy of neem in phenological regulation.

This lack of root growth stimulation is at odds with studies highlighting the soil-mediated benefits of neem (Qayyum et al., 2024) and implies that applications target primarily the shoot systems. This is consistent with the findings of Adusei and Azupio (2022), in which negligible root responses were observed under non-stress conditions. However, the antioxidant properties (Akhtar et al., 2022) of neem under abiotic stressors such as drought may be indirectly supportive of root health, which deserves further investigation in stressful environments.

The study's focus on higher neem concentrations (up to 15%) goes beyond previous investigations, which most commonly used lower dose (e.g., 5–10%) road-tested data. The strong effects at 15% indicate that *Zinnia* tolerates and responds favourably to elevated neem levels, but thresholds for phytotoxicity were not explored. Karmakar et al. (2023) warned against overdosing sensitive species, but *Zinnia*'s resilience presented here makes it a prime candidate for neem-based bio-stimulation.

CONCLUSION

It is concluded that the foliar application of neem extract has excellent potential for improving the growth and development of these plants, *Z. elegans* L., a practice compatible with sustainable horticulture. These encouraging results behind the enhancement of plant efficiency indicate the belief that neem extract can be considered a bio-stimulant that has a role either in the variation of the morphological characteristics of plants or in the tolerance to different types of stress. These outcomes are dose-dependent, indicating that clinical applications must be made to maximise efficacy and minimise toxicity. These results support using neem extract as the natural, eco-friendly alternative to chemical agrochemicals in ornamental cultivation.

DECLARATION OF COMPETING INTERESTS

The authors declare no conflict of interest.

AUTHOR CONTRIBUTION STATEMENT

Hamza Niaz: Conceive the idea, Collected the data. **Muhammad Uzair Amjad:** Execute the experiment. **Muhammad Rizwan:** Write the research article.

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Not available.

ETHICAL STATEMENT

Not applicable.

AVAILABILITY OF DATA AND MATERIAL

All data is published in this research article.

INFORMED CONSENT

Not applicable.

CONSENT FOR PUBLICATION

All the authors submitted consent to publish this research article in the 'Journal of Horticulture Sciences and Technology'.

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