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Dose-dependent Optimization of NAA Foliar Sprays for Enhanced Morpho-Physiological Traits and Yield in Chilli cv. Kashi Ratna under Varanasi Conditions

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study aims to evaluate the influence of foliar-applied Naphthalene Acetic Acid (NAA) on the growth, yield and quality attributes of chilli (*Capsicum annuum* L.) cv. Kashi Ratna. The present investigation was carried out during the winter season of 2023–24 at the Vegetable Research Farm, Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University,

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Varanasi, Uttar Pradesh, India. The experiment was laid out in a Randomized Block Design with nine treatments consisting of NAA concentrations ranging from 10, 20, 30, 40, 50, 60, 70 and 80 ppm along with control, replicated thrice. The treatments included T1 (NAA 10 ppm), T2 (NAA 20 ppm), T3 (NAA 30 ppm), T4 (NAA 40 ppm), and T5 (NAA 50 ppm), with T6-T9 representing higher concentrations and control. Two foliar sprays were administered at 30 and 45 DAT. Significant improvements in vegetative traits were recorded under NAA treatments, with 50 ppm (T_5) exhibiting the maximum plant height (74.13 cm), highest branching (9.94 branches) and greatest chlorophyll content (62.72 SPAD). Reproductive parameters also responded positively, as 60 ppm NAA (T_6) induced the earliest first flowering (50.91 days) and 50% flowering (55.43 days). Yield attributes showed substantial enhancement, with T_5 producing the highest number of fruits per plant (237.85), fruit weight (2.86 g), yield per plant (679.82 g), yield per plot (16.99 kg) and productivity (251.78 q ha^{-1}), representing a notable improvement over the control. Quality traits also improved markedly under NAA, as evidenced by increased ascorbic acid content (95.74 mg/100 g) and reduced fruit pH (6.31) in T_5. Overall, the study demonstrates that foliar application of NAA, particularly at 50 ppm, optimizes growth, enhances reproductive efficiency, improves fruit quality and significantly increases yield under the agro-climatic conditions of Varanasi, making it a highly effective practice for chilli cultivation.

Keywords: Foliar application; NAA; yield; agro-climatic conditions; chilli cultivation.

1. INTRODUCTION

Chilli holds special significance due to its economic and culinary value (Padmanabhan *et al*., 2016). Vegetables supply essential nutrients including vitamins, minerals, carbohydrates, proteins and dietary fiber. India is the world's second-largest vegetable producer after China, with a significant vegetarian population. As per ICMR recommendation 300 g vegetables per day as 125 g leafy vegetables, 100 g roots and tubers and 75 g other vegetables (Anonymous, 2020). Vegetables contributed 59.25% (214.56 Mt) of India's total horticulture production of 362.086 Mt in 2024–25 (Anonymous, 2024). Chilli (*Capsicum annuum* L.) is an important spice crop widely cultivated across India. It belongs to Solanaceae, which includes about 200 species and 90 genera, and has chromosome number 2n=24 (Veishnav *et al*., 2012). Its wild progenitor is *Capsicum annuum* var. *minimum*. The genus comprises five domesticated and twenty wild species, including C. *annuum* var. *annuum*, C. *annuum* var. *pendulum*, C. *annuum* var. *chinense*, C. *annuum* var. *frutescens* and C. *annuum* var. *pubescens* (Swamy, 2023). Among these, C. *annuum* var. *annuum* is the most widely cultivated (Liu *et al*., 2023), selected over time to produce the hot peppers used worldwide (Lin *et al*., 2013). Although generally 2n=24, aneuploids (2n=25) and polyploids (2n=36, 48) have also been reported. Plants are herbaceous, up to 1.5 m tall, with semi-woody bases and pubescent green stems (Swamy, 2023). Flowers are perfect, possessing six to seven fused sepals, seven stamens with bilocular pollen sacs that dehisce terminally or internally and a superior ovary formed by two to three carpels (Dhall *et al*., 2011). Chilli originated in Mexico, Guatemala and Bulgaria and was introduced to India by the Portuguese in the 16th century (Mehta *et al*., 2017). Due to its pungency, aroma and flavor, it is used in almost all Indian cuisines. Fruits are rich in vitamins A, E and C and valued for their color and pungency. Chilli serves the culinary, beverage and pharmaceutical industries. The substance that is responsible for pungency in chilli is capsaicin and the bright red colour at the ripening stage is due to the pigment capsanthin. Capsaicin, a compound which has potential health benefits, including pain relief, improved digestion, and boosting metabolism (Suhaini et al., 2023). Major hot chilli producers include India, China, Indonesia, Korea, Pakistan, Turkey and Sri Lanka, while mild types are grown in Bulgaria, Romania, Spain and Hungary. In India, chilli covers 9.09 lakh ha with production of 2.78 Mt and productivity of 3.24 t ha^{-1} (Anonymous, 2024–25). Andhra Pradesh contributes 57% of national production. Research on plant growth regulators (PGRs) in solanaceous crops indicates that PGRs can enhance chilli yield by reducing flower and fruit drop (Kumari *et al*., 2016; Veishnav *et al*., 2012). Improving fruit set and minimizing flower drop are key strategies for increasing productivity. PGRs, after fertilizers and pesticides, are considered vital tools because they strengthen source-sink relationships and enhance translocation of photosynthates, thereby improving fruit retention. Foliar spraying of NAA is particularly effective in reducing flower and fruit drop in chilli, but limited information exists regarding the combined effects of NAA and ethrel on seed yield and quality (Anolisa *et al*., 2020). Improvement of growth characteristics of plants through the application of micronutrients might be due to the enhancement of various physiological and metabolic processes in plants (Hatwar et al., 2003; Azad et al., 2021; Hossain et al., 2025). Growth substances such as GA_3, 2,4-D and NAA regulate physiological and biochemical processes influencing plant growth, flowering, fruit set, ripening and seed quality (Singh *et al*., 2017). Auxins like NAA stimulate cell division and elongation, shoot growth, photosynthesis, RNA synthesis and membrane permeability, while low concentrations of 2,4-D also act as auxins promoting elongation (Singh *et al*., 2019). PGRs help modify plant traits rapidly within a single season (Rademacher, 2015). NAA specifically enhances vegetative growth by stimulating cambial activity (Roberts, 2012). In horticulture, NAA improves root initiation, reduces fruit drop, enhances fruit retention and ensures uniform fruit development (Rahman *et al*., 2023). It also regulates plant architecture, delays senescence and improves postharvest quality, significantly boosting productivity when applied at proper concentrations (Sarker *et al*., 2009). Despite progress, region-specific studies on optimized NAA use are limited (Sahu *et al*., 2019). Challenges such as high flower and fruit drop and fluctuating demand for quality chilli underline the need for location-specific, scientifically validated protocols, especially under Varanasi's agro-climatic conditions. Therefore, the objective of the present study is to bridge this gap and generate practical recommendations to enhance chilli yield and quality, benefiting farmers and the horticulture sector.

2. MATERIALS AND METHODS

The field experiment was conducted during the winter season of 2023–24 at the Vegetable Research Farm, Department of Horticulture, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India. The site lies at 25°26'4" N latitude, 83°99'3" E longitude and 129.23 m altitude, representing a humid subtropical climate with temperatures ranging between 7.1–40.9°C and relative humidity from 24–97% during the crop period. The soil of the experimental field was sandy clay loam with a pH of 7.3, organic carbon 0.46%, and available N, P_2O_5 and K_2O of 173, 16.8 and 164 kg ha^{-1}, respectively. The study employed a randomized block design consisting of nine treatments of NAA (10, 20, 30, 40, 50, 60, 70 and 80 ppm and a control), replicated three times, totalling 27 plots. The chilli variety 'Kashi Ratna' was raised in a prepared nursery and transplanted at 60 × 45 cm spacing. Two foliar sprays of NAA were applied at 30 and 45 DAT. Each plot contained five rows and from every plot five plants were randomly tagged for recording biometric, yield and quality parameters. Observations included plant height, number of branches, internodal length, chlorophyll content, flowering behaviour, fruit yield attributes and biochemical qualities such as TSS, pH and ascorbic acid. Standard laboratory procedures were followed for vitamin C estimation. Data were subjected to Analysis of Variance (ANOVA) and treatment means were compared using the critical difference (CD) at the 5% level, while SEm ± and SEd ± were computed to assess statistical precision.

3. RESULTS AND DISCUSSION

3.1 Modification of Growth Dynamics

3.1.1 Regulation of plant height

Plant height exhibited a marked enhancement with NAA treatments, where T_5 recorded the maximum height at both 60 and 90 DAT (37.10 cm and 74.13 cm). This superior growth may be attributed to increased cell division and elongation stimulated by auxins, which enhance metabolic activity, cell wall extensibility and overall vegetative vigor. The findings align with the observations of Anbarasi *et al*. (2022) and Kumari *et al*. (2025) who similarly reported improved plant height in chilli with NAA application.

3.1.2 Optimization of branching pattern

Branching pattern showed a progressive increase with crop age, with branch numbers rising from 4.17–6.29 at 60 DAT to 7.41–9.94 at 90 DAT. Treatment T_5 (50 ppm) recorded the highest branch count at both stages, outperforming the control by 50.8% at 60 DAT and 34.1% at 90 DAT. The significant rise in branching could be linked to NAA-induced stimulation of axillary bud activation, enhanced photosynthesis and increased nutrient mobilization, all of which promote vigorous vegetative growth. These outcomes are well supported by earlier studies in chilli by Tamilselvi (2014) and Kumari *et al*. (2025), and in brinjal by

Patel *et al*. (2012), all of which highlight the branching-promotive effects of NAA at 40–60 ppm.

3.1.3 Alteration of chlorophyll content

Chlorophyll content, measured as SPAD value, was also substantially improved, with T_5 showing the maximum reading of 62.73 SPAD units. Auxin-induced enhancement in chloroplast number, nutrient assimilation, amino acid synthesis and hormonal balance likely contributed to this increase in chlorophyll concentration, ultimately elevating photosynthetic rates. These findings correspond with the reports of Tapadiya *et al*. (2018), Singh *et al*. (2024) and Kumar *et al*. (2018), who also noted higher chlorophyll levels with NAA application.

3.1.4 Optimization of flower initiation

The reproductive transition was also accelerated under NAA treatments. T_6 (60 ppm) induced earliest first flowering (50.91 days) and 50% flowering (55.43 days), advancing phenology by 11–12% compared to control. Auxins are known to modulate endogenous hormonal balance, particularly influencing interactions between auxins and cytokinins, thereby accelerating floral initiation and enhancing assimilate flow toward developing reproductive tissues. Comparable trends were reported by Singh *et al*. (2012) and Rathore *et al*. (2022).

3.2 Improvement of Yield Attributes

3.2.1 Influence on number of fruits in plants

The number of fruits per plant was highest in T_5 (237.85 fruits), followed by T_6 and T_4. Improved fruit set and delayed ovule senescence under NAA spray may have facilitated better pollen tube penetration and retention of developing fruits. These results are supported by Tamilselvi *et al*. (2019) and Dahal *et al*. (2022), who documented enhanced fruit number in chilli under NAA.

3.2.2 Modification of fruit length

Fruit length (9.61 cm) and width (0.92 cm) were also highest in T_5, followed by T_6 and T_4. Auxins are widely reported to promote fruit elongation through cell expansion and division, which aligns with the observations of Kumari *et al*. (2016) and Tapadiya *et al*. (2018).

3.2.3 Optimization of fruit weight

fruit weight showed a similar pattern, with T_5 producing the heaviest fruits (2.86 g). Enhanced translocation of nutrients and increased photosynthate allocation likely facilitated greater biomass accumulation in fruits. These findings match those of Sanodiya *et al*. (2017) and Singh *et al*. (2017), who reported significantly increased fruit weight with NAA.

3.2.4 Effect on Fruit yield per plant

Under NAA, fruit yield per plant increased significantly; T_5 had the highest yield of 679.8 g, 70.5% more than the control. Additionally, yields were considerably greater for T_6 and T_4. The improvement can be ascribed to improved physiological efficiency, increased fruit weight, and improved fruit retention. Gare *et al*. (2017) and Patel *et al*. (2016) all reported similar outcomes.

3.2.5 Influence on fruit yield per plot and hectare

Similar trends were seen in the fruit production per plot, with T_5 producing 16.99 kg compared to the control's 9.97 kg. This is consistent with research by Arora *et al*. (2014) and Faruk *et al*. (2023), who also found that foliar NAA at 50 ppm significantly increased yield. Due to greater fruit set, bigger fruits, and increased photosynthetic efficiency, T_5 had the best yield (251.78 q/ha) per hectare. Similar increases were reported in okra by Sanodiya *et al*. (2017), brinjal by and chilli by Singh *et al*. (2024).

3.2.6 Manipulation of number of seeds

The number of seeds per fruit increased as well; T_6 had the largest amount (76.70), followed by T_3 and T_4. The higher seed set could be the outcome of more effective fertilization when auxin is applied. According to Raj *et al*. (2016) and Kalshyam *et al*. (2011), these results are consistent.

3.3 Quality Trait Evaluation

3.3.1 ph Response to treatments

Under NAA, fruit pH dramatically dropped, with T_5 exhibiting the lowest value (6.31) in comparison to the control (7.22). This acidification, which improves flavor and shelf life, is probably caused by auxin-induced increases in organic acid production. Singh *et al*. (2024) and Kumari *et al*. (2016) reported similar results.

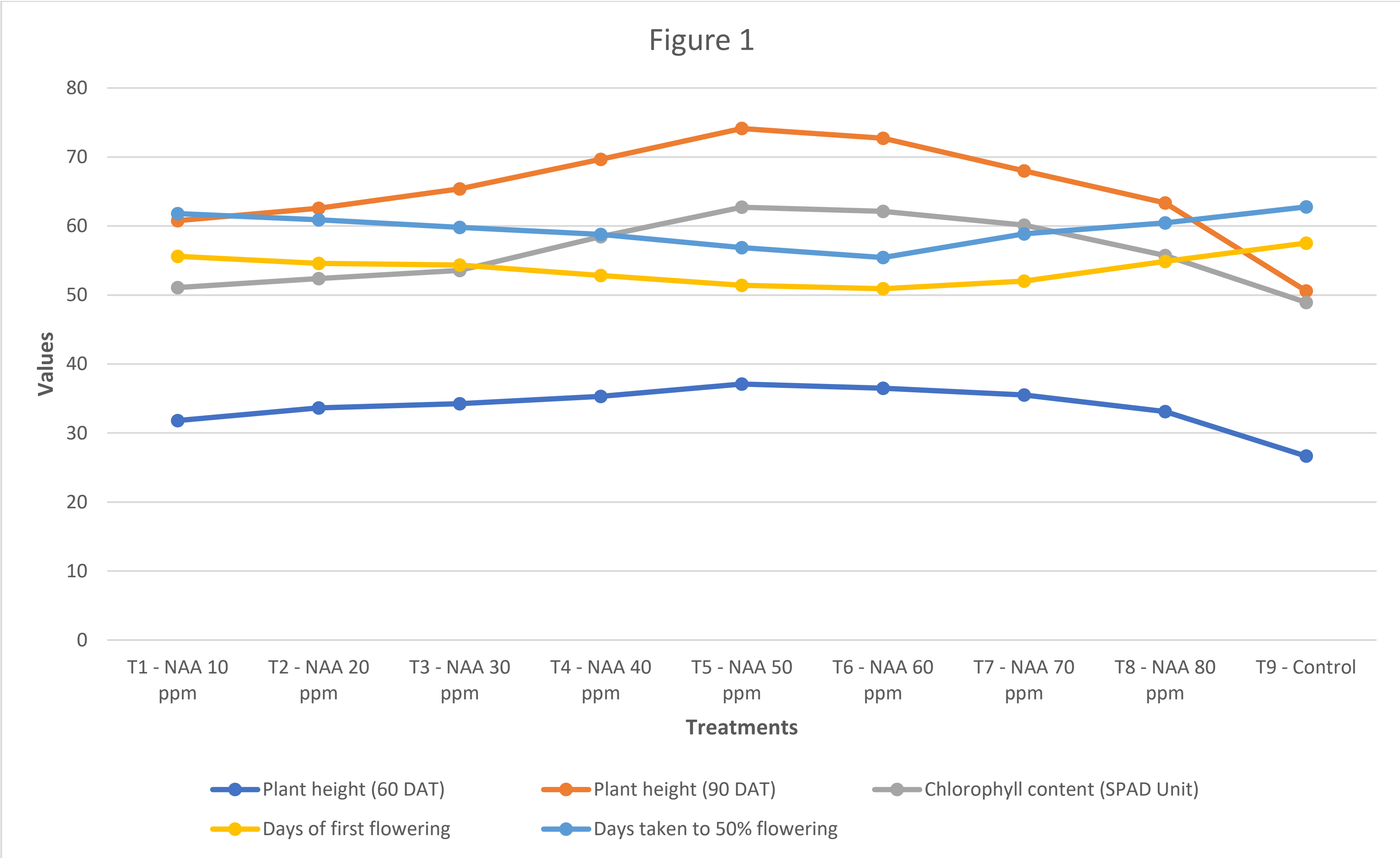


Figure 1
80
70
60
50
40
30
20
10
0
Values
T1 - NAA 10 ppm
T2 - NAA 20 ppm
T3 - NAA 30 ppm
T4 - NAA 40 ppm
T5 - NAA 50 ppm
T6 - NAA 60 ppm
T7 - NAA 70 ppm
T8 - NAA 80 ppm
T9 - Control
Treatments
Plant height (60 DAT)
Plant height (90 DAT)
Chlorophyll content (SPAD Unit)
Days of first flowering
Days taken to 50% flowering

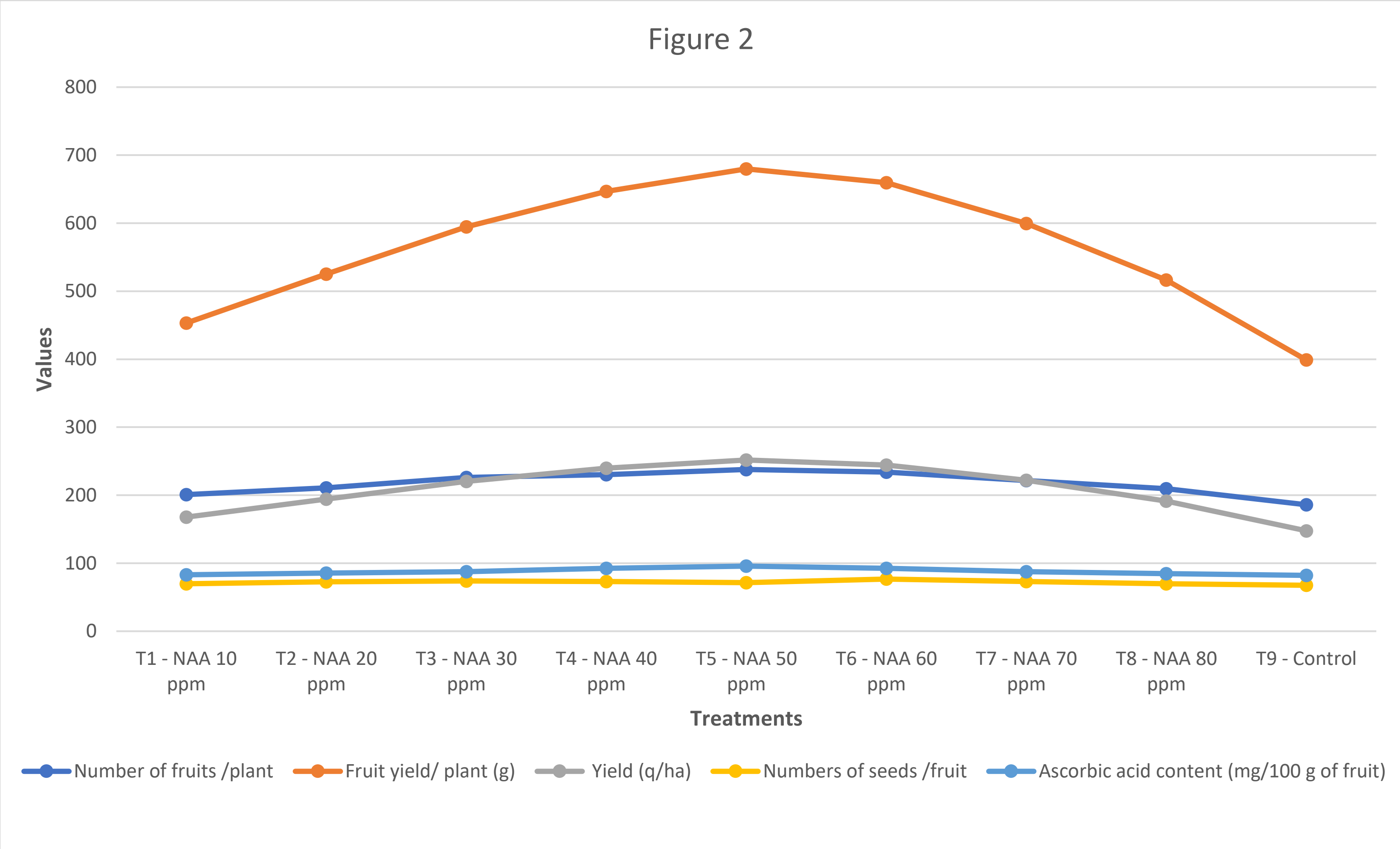
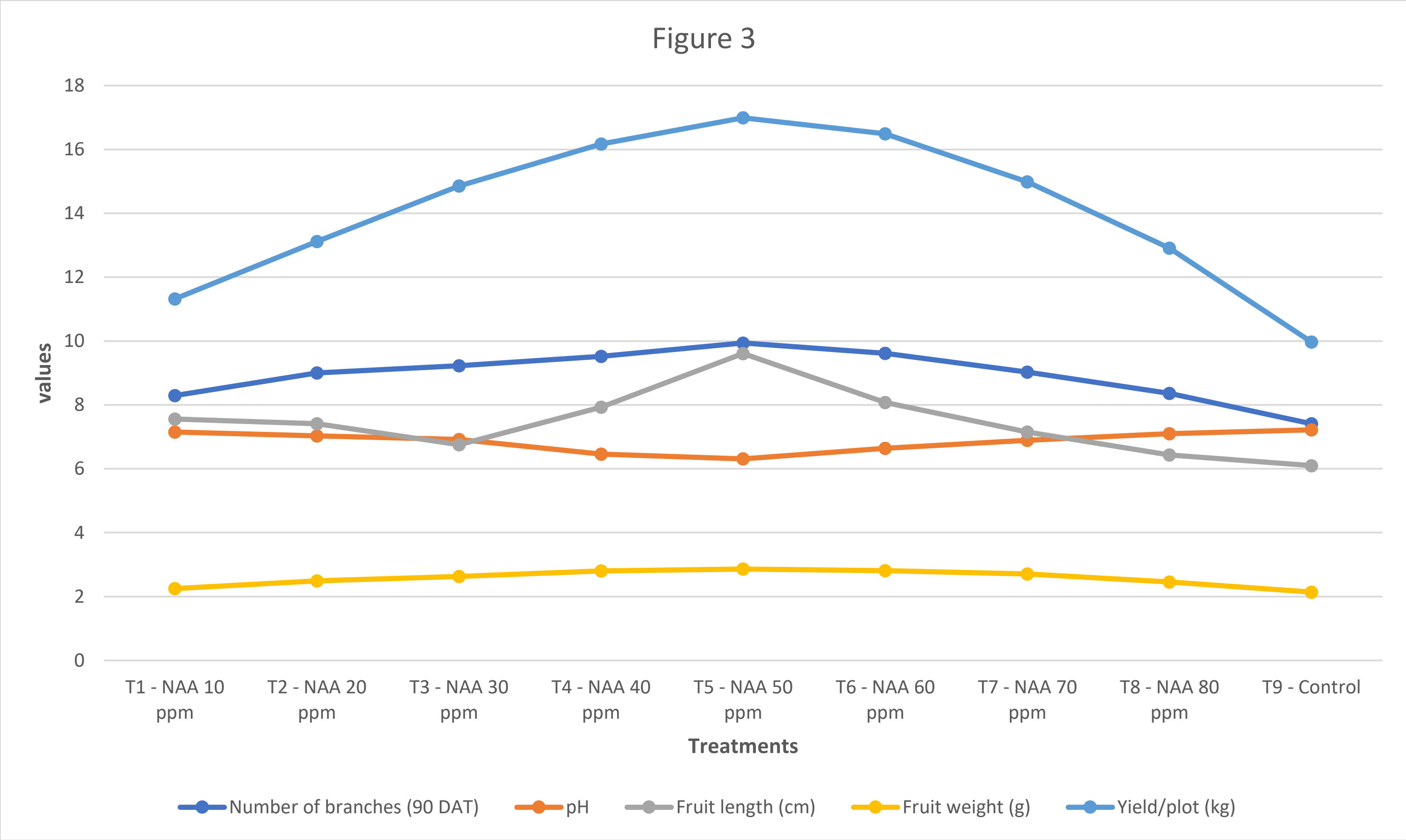


Figure 2
Values
800
700
600
500
400
300
200
100
0
T1 - NAA 10 ppm
T2 - NAA 20 ppm
T3 - NAA 30 ppm
T4 - NAA 40 ppm
T5 - NAA 50 ppm
T6 - NAA 60 ppm
T7 - NAA 70 ppm
T8 - NAA 80 ppm
T9 - Control
Treatments
Number of fruits /plant
Fruit yield/ plant (g)
Yield (q/ha)
Numbers of seeds /fruit
Ascorbic acid content (mg/100 g of fruit)



Figs. 1-3. Treatment-Induced ascorbic acid modifications

3.3.2 Treatment-Induced ascorbic acid modifications

Additionally, T_5 had the highest ascorbic acid level (95.74 mg/100 g), indicating that NAA promotes vitamin production, membrane permeability, and enzymatic activity. According to Kumari *et al*. (2016), and Singh *et al*. (2024), these results are consistent.

4. CONCLUSION

The study unequivocally showed that applying NAA topically greatly improved the chilli's growth, yield, and quality characteristics. The tallest plants, highest branching, longest internodes, maximum fruit number, size, weight, and superior yields per plant, plot, and hectare were all produced by NAA at 50 ppm (T_5), which proved to be the most successful treatment of all. Chlorophyll content, ascorbic acid, TSS, and seed weight were among the quality indices that were highest in T_5, although flowering and fruit set were hastened by 60 ppm (T_6). Under the specified agroclimatic circumstances, 50 ppm NAA was shown to be the ideal concentration for optimizing vegetative growth, reproductive efficiency, fruit quality, and productivity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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