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Effect of foliar application of plant bio-regulators and micronutrients on fruit set, yield and fruit quality of mango (*Mangifera indica* L.) cv. 'Amrapali'

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Abstract

Pre-harvest fruit drop is one of the major constraints limiting fruit yield and quality in mango, whereas the judicious use of plant bio-regulators and micronutrients can improve fruit retention and productivity. The present study, therefore, aimed to evaluate the effect of foliar application of GA₃, NAA and borax on fruit retention, yield and fruit quality of mango cv. 'Amrapali'. A randomized block design comprising ten treatments, including three concentrations each of GA₃ (20, 40 and 60 ppm), NAA (15, 20 and 25 ppm), borax (0.2, 0.4 and 0.6%) and a water spray as the control was conducted during 2022-23. Among the treatments, foliar application of GA₃ at 20 ppm (T₁) produced the highest number of fruits per panicle (6.3), fruit retention (7.67%), pulp content (74.3%), pulp-to-stone ratio (7.00), fruit weight (241 g), fruit volume (248.8 cm³), and fruit yield (288.8 q ha⁻¹), followed by NAA at 25 ppm (T₆). The lowest fruit drop was also recorded with GA₃ at 20 ppm, followed by NAA at 25 ppm. In comparison with the plant bio-regulators, borax treatments produced relatively smaller improvements in the evaluated yield and fruit quality attributes. Therefore, foliar application of GA₃ at 20 ppm can be recommended for improving fruit retention, yield, and fruit quality of mango cv. Amrapali under the agro-climatic conditions of eastern Uttar Pradesh.

Keywords: *Mangifera indica*, GA₃, NAA, borax, fruit retention, fruit yield

Introduction

Mango (*Mangifera indica* L.), belonging to the family Anacardiaceae, is one of the most important fruit crops cultivated in tropical and subtropical regions of the world. Owing to its exceptional flavour, aroma, nutritional value and wide consumer acceptance, it is popularly referred to as the "King of Fruits" and occupies a prominent position in the global fruit industry. India, recognized as the centre of origin and diversity of mango, is the world's largest producer, with the crop occupying 2393.86 thousand hectares and producing 22662.89 thousand metric tons annually (NHB 2024) [15]. Despite its commercial importance, mango productivity is often constrained by poor fruit retention and excessive pre-harvest fruit drop, which substantially reduce marketable yield and fruit quality. Therefore, developing effective management strategies to improve fruit retention and productivity remains a major objective in mango cultivation. Fruit retention and final yield in mango are largely governed by hormonal balance and adequate nutrient availability during flowering and fruit development. Plant bio-regulators and micronutrients have therefore become integral components of modern orchard management because they regulate physiological processes associated with flowering, fruit set, fruit retention, and fruit development in mango (Kumar *et al.* 2018) [10]. Foliar application is considered an efficient means of supplying these compounds because nutrients and growth regulators applied directly to the foliage are rapidly absorbed and translocated to metabolically active tissues, thereby fulfilling the nutritional and physiological requirements of the developing crop (Tripathi and Kumar 2022) [26]. Furthermore, foliar nutrition becomes particularly important under environmental stress or unfavourable soil conditions, where root uptake of nutrients is often restricted (Marschner 2012) [12]. Timely pre-harvest foliar application of plant bio-regulators and micronutrients has also been reported to reduce fruit drop while improving fruit retention, yield, and fruit quality in mango (Verma *et al.* 2025) [28].

Among the various plant bio-regulators used in mango cultivation, gibberellic acid (GA₃) and naphthalene acetic acid (NAA) have received considerable attention because of their beneficial effects on fruit retention and development. Foliar application of GA₃ has been reported to enhance fruit retention, fruit size, fruit weight, and overall productivity by promoting cell division and cell elongation during fruit growth (Ahmed *et al.* 2012; Verma *et al.* 2025) [2, 28]. Similarly, NAA minimizes bud, flower, and fruit abscission by maintaining hormonal balance, thereby improving fruit retention, fruit size, yield, and fruit quality (Davenport 2007) [5]. In addition to plant bio-regulators, boron is an essential micronutrient that plays a vital role in reproductive development by regulating pollen germination, pollen tube elongation, fertilization, cell wall formation, and carbohydrate translocation, thereby improving fruit set, fruit development, and fruit quality. Owing to these physiological functions, foliar application of boron has been widely recognized as an effective strategy for enhancing fruit formation and productivity in mango (Saran and Kumar 2011) [22]. Boron is particularly important for producing viable pollen and promoting rapid pollen tube growth, which are essential for successful fertilization and fruit set (El-Sheikh *et al.* 2007) [6]. It also indirectly influences the activity of plant hormones and dehydrogenase enzymes involved in plant metabolism (Marschner 2012) [12]. However, because boron is weakly adsorbed by soil particles and is readily lost through leaching, its availability to plants is often limited under field conditions (Raja *et al.* 2005) [20]. Consequently, foliar application has emerged as an efficient approach for correcting boron deficiency and improving reproductive performance. Previous studies have demonstrated that foliar boron application enhances fruit set per panicle, fruit weight, and fruit volume in mango (Pavithra *et al.* 2019; Bibi *et al.* 2019; Khan *et al.* 2022) [18, 4, 9]. Similar beneficial effects have also been reported in Japanese pear (Lee *et al.* 2009) [11]; strawberry (Saridaş *et al.* 2021) [23] and avocado (Hapuarachchi *et al.* 2022) [8]. Although several studies have demonstrated the beneficial effects of GA₃, NA, and boron on mango production, however, their comparative effectiveness depends on cultivar, concentration and prevailing agro-climatic conditions. Information regarding the optimum concentrations of these foliar treatments for improving fruit

retention, yield and fruit quality in mango cv. 'Amrapali' under the agro-climatic conditions of eastern Uttar Pradesh remains limited. Therefore, the present investigation was undertaken to evaluate the effect of different concentrations of GA₃, NAA, and borax on fruit retention, yield and fruit quality of mango cv. 'Amrapali'.

Materials and Methods

Experimental site and treatments details

The experiment was conducted during the 2022-23 growing season at the Main Experiment Station (Horticulture), Acharya Narendra Deva University of Agriculture and Technology, Narendra Nagar (Kumarganj), Ayodhya, Uttar Pradesh, India. Thirty healthy and uniformly growing mango (*Mangifera indica* L.) trees of cv. 'Amrapali' were selected for the study. The experiment was laid out in a randomized block design comprising ten treatments with three replications. The treatments consisted of foliar application of GA₃ at 20 ppm (T₁), 40 ppm (T₂) and 60 ppm (T₃); NAA at 15 ppm (T₄), 20 ppm (T₅) and 25 ppm (T₆); borax at 0.2% (T₇), 0.4% (T₈) and 0.6% (T₉); and water spray as the control (T₁₀). Foliar sprays were applied twice, with the first application during the second fortnight of March and the second after fruit set during the second fortnight of April. Observations on fruit set, fruit drop, and fruit retention were recorded at 15-day intervals until harvest. All other orchard management practices were maintained uniformly across the experimental trees throughout the study. Standard phytosanitary measures, including the application of recommended insecticides and fungicides, were adopted as required to keep the trees free from pests and diseases. Manual weeding was carried out periodically to maintain weed-free basins and minimize competition for nutrients and soil moisture.

Measurement of fruit set, fruit drop and fruit retention

The number of fruits set per panicle was recorded by counting all fruits on tagged panicles after fruit set and the average number of fruits per panicle was calculated. Fruit drop was determined by tagging representative panicles in all four directions of each experimental tree at the pea stage of fruit development. The number of fruits was recorded at the pea stage and again at fruit maturity. Fruit drop was expressed as a percentage using the following equation:

$$\text{Fruit drop (\%)} = \frac{\text{Number of fruits at pea stage} - \text{Number of fruits retained at maturity}}{\text{Number of fruits at pea stage}} \times 100$$

Fruit retention was calculated from the initial fruit set and the number of fruits retained until maturity using the following equation:

$$\text{Fruit retention (\%)} = \frac{\text{Number of fruits retained at maturity}}{\text{Number of fruits at initial fruit set}} \times 100$$

Measurement of fruit physical characteristics

Three representative fruits from each replication were randomly selected for recording physical characteristics. Average fruit weight (g) was determined using a digital electronic balance. Polar diameter (fruit length) was measured individually using a digital vernier caliper and expressed in centimetres (cm). Fruit volume (cm³) was determined by the water displacement method. Specific gravity was calculated using the following equation:

$$\text{Specific gravity} = \frac{\text{Fruit weight (g)}}{\text{Fruit volume (cm}^3\text{)}}$$

After recording the fruit weight, pulp was separated from the stone and weighed individually. Pulp percentage and stone percentage were calculated as follows:

$$\text{Pulp (\%)} = \frac{\text{Pulp weight}}{\text{Fruit weight}} \times 100$$

$$\text{Stone (\%)} = \frac{\text{Stone weight}}{\text{Fruit weight}} \times 100$$

Likewise, the pulp-to-stone ratio was calculated using the equation:

$$\text{Pulp : Stone ratio} = \frac{\text{Pulp weight}}{\text{Stone weight}}$$

Measurement of fruit yield

Fruits harvested from each experimental tree were weighed immediately after harvest and fruit yield was expressed as kilograms per tree (kg tree⁻¹). Fruit yield per hectare was calculated from the yield per tree and the total number of trees per hectare using the following equation:

$$\text{Fruit yield (q ha}^{-1}\text{)} = \frac{\text{Yield per tree (kg)} \times \text{Number of trees per hectare}}{100}$$

Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for a randomized block design (RBD) following the standard procedure described by Gomez and Gomez (1984). The significance of treatment effects was tested at the 5% probability level ($p \leq 0.05$). Standard error of the mean [SE(m)±] and critical difference (CD) at the 5% level of significance were calculated to compare the treatment means.

Results and Discussion

Fruit set, fruit drop and fruit retention

The foliar application of plant bio-regulators and micronutrients significantly influenced fruit set, fruit drop, and fruit retention in mango cv. 'Amrapali' (Table 1). Among the treatments, foliar application of GA₃ at 20 ppm produced the highest number of fruits per panicle (6.3), which was statistically at par with NAA at 25 ppm (5.7) and NAA at 15 ppm (5.6), whereas the lowest number of fruits per panicle (4.1) was recorded in the control (T₁₀). Likewise, GA₃ at 20 ppm recorded the lowest fruit drop (92.33%) and the highest fruit retention (7.67%), followed by NAA at 25 ppm, while the control exhibited the highest fruit drop (98.18%) and the lowest fruit retention (1.82%).

The improvement in fruit set and retention following foliar application of GA₃ may be attributed to its role in regulating hormonal balance during the early stages of fruit development. Exogenous application of gibberellins reduces the formation of the abscission layer by maintaining higher endogenous auxin levels, thereby minimizing premature fruit drop and promoting fruit retention (Agusti 2000) [1]. In addition, GA₃ are known to enhance cell division and cell elongation in developing fruits, resulting in improved sink strength and greater retention of young fruits. Further, the favourable response observed with NAA application may also similarly be associated with its ability to suppress abscission by maintaining auxin concentration in the fruit stalk, thereby reducing physiological fruit drop and improving fruit retention. In contrast, untreated trees experienced greater fruit drop because of the absence of exogenous hormonal regulation during the critical stages of fruit development. The present findings are in agreement with those of Singh *et al.* (2017) [24], Kumar *et al.* (2018) [10], Patel *et al.* (2018) [17] and Verma *et al.* (2025) [28], who reported improved fruit retention and reduced fruit drop following foliar application of GA₃ in mango. Similar responses following NAA application have also been reported by Tripathi *et al.* (2019) [27], whereas Bhowmick and Banik (2011) [3] observed maximum fruit retention in mango following GA₃ application.

On the other hand, borax treatments produced relatively smaller improvements in these parameters. This response

may be attributed to the distinct physiological role of boron, which primarily functions as a micronutrient involved in pollen germination, pollen tube growth, fertilization, cell wall formation, and carbohydrate transport rather than directly regulating hormonal balance associated with fruit abscission. Since boron mainly facilitates successful fertilization during the flowering stage, its influence on reducing physiological fruit drop after fruit set is generally less pronounced than that of plant growth regulators such as GA₃ and NAA. However, the experimental orchard may not have been sufficiently deficient in boron for foliar application to produce responses comparable to those observed with the plant bio-regulators.

Table 1: Effect of foliar spray of plant bio-regulators and micro-nutrients on number of fruits per panicle, fruit drop and fruit retention of mango cv. 'Amrapali'.

Treatment	Number of fruits per panicle	Fruit drop (%)	Fruit retention (%)
T ₁ -GA ₃ 20 ppm	6.3	92.33	7.67
T ₂ -GA ₃ 40 ppm	5.0	92.95	4.34
T ₃ -GA ₃ 60 ppm	4.8	93.58	6.42
T ₄ -NAA 15 ppm	5.6	95.66	7.12
T ₅ -NAA 20 ppm	5.4	93.75	6.25
T ₆ -NAA 25 ppm	5.7	92.88	7.05
T ₇ -Borax 0.2 ppm	5.3	96.40	3.60
T ₈ -Borax 0.4 ppm	5.5	94.62	5.38
T ₉ -Borax 0.6 ppm	5.2	96.95	3.05
T ₁₀ -Control	4.1	98.18	1.82
SEm±	0.1	1.93	0.11
CD at 5%	0.3	5.74	0.32

Pulp percentage, stone percentage and pulp-to-stone ratio

Foliar application of plant bio-regulators and micronutrients significantly influenced pulp percentage, stone percentage, and pulp-to-stone ratio in mango cv. 'Amrapali' (Table 2). Among the treatments, GA₃ at 20 ppm recorded the highest pulp percentage (74.3%) and pulp-to-stone ratio (7.00), which were statistically at par with NAA at 25 ppm, recording 72.4% pulp and a pulp-to-stone ratio of 6.64. Conversely, the lowest pulp percentage (60.2%) and pulp-to-stone ratio (3.62) were observed in the untreated control. In contrast, the lowest stone percentage (10.6%) was recorded with GA₃ at 20 ppm, followed by NAA at 25 ppm (10.9%), whereas the highest stone percentage (16.6%) was observed in the control treatment. The improvement in pulp percentage and pulp-to-stone ratio following foliar application of GA₃ may be attributed to its stimulatory effect on cell division and cell elongation during fruit development, resulting in greater accumulation of pulp tissue and enhanced fruit growth. Gibberellins are also known to improve the translocation and utilization of photosynthates towards developing fruits, thereby increasing sink strength and promoting greater deposition of assimilates in the edible pulp. Likewise, NAA may have enhanced pulp development by reducing premature fruit drop and improving the movement of carbohydrates to the developing fruits through better hormonal regulation. The corresponding reduction in stone percentage under these treatments is likely a consequence of greater pulp development rather than a reduction in stone size, thereby increasing the edible portion of the fruit. Moreover, the increase in pulp percentage may be due to more absorption of water influenced by these plant bio-regulators which

might have ultimately increased the volume of intercellular spaces in the pulp. Although borax application also improved these attributes compared with the untreated control, its effect was less pronounced than that of GA₃ and NAA because boron primarily supports reproductive processes and carbohydrate transport rather than directly stimulating fruit enlargement and pulp development. The present findings are in agreement with those of Tripathi *et al.* (2019) [27] in mango; Khan *et al.* (2022) [9] in mango; Singh *et al.* (2023) [25] in mango and Priya *et al.* (2023) [19] in ber, who reported similar improvements in pulp content and fruit quality following foliar application of plant growth regulators in mango.

Table 2: Effect of foliar Spray of plant bio-regulators and micro-nutrients on Pulp, Stone and Pulp/Stone of mango cv. 'Amrapali'.

Treatment	Pulp (%)	Stone (%)	Pulp/Stone ratio
T ₁ -GA ₃ 20 ppm	74.3	10.6	7.00
T ₂ -GA ₃ 40 ppm	67.8	13.9	4.87
T ₃ -GA ₃ 60 ppm	65.0	14.1	4.60
T ₄ -NAA 15 ppm	66.0	13.9	4.76
T ₅ -NAA 20 ppm	69.2	13.2	5.24
T ₆ -NAA 25 ppm	72.4	10.9	6.64
T ₇ -Borax 0.2 ppm	67.1	13.8	4.86
T ₈ -Borax 0.4 ppm	68.4	13.6	5.02
T ₉ -Borax 0.6 ppm	67.9	13.7	4.93
T ₁₀ -Control	60.2	16.6	3.62
SEm±	1.4	0.2	0.10
CD at 5%	4.1	0.8	0.31

Yield, yield-attributing traits and specific gravity

The data presented in Tables 3 and 4 revealed that the fruit yield, yield attributing traits and specific gravity of mango cv. 'Amrapali' were significantly influenced by foliar application of plant bio-regulators and micronutrients. Trees treated with GA₃ at 20 ppm produced significantly larger fruits, as evidenced by the maximum polar diameter (9.15 cm), fruit weight (241 g), fruit volume (248.8 cm³), and specific gravity (1.09). These improvements resulted in the highest fruit yield of 16.7 kg tree⁻¹, corresponding to 288.8 q ha⁻¹. In contrast, the untreated control (T₁₀) produced the smallest fruits, recording the lowest polar diameter (7.95 cm), fruit weight (188 g), fruit volume (189.4 cm³), specific gravity (0.90), fruit yield (9.8 kg tree⁻¹), and yield (156.8 q ha⁻¹).

The progressive enhancement of fruit size and yield under GA₃ treatment suggests that its influence extended beyond improving fruit retention and continued throughout fruit development. The observed increase in fruit size and weight indicates enhanced partitioning of photoassimilates towards developing fruits, enabling sustained dry matter accumulation throughout the fruit development period. Consequently, fruits attained greater volume and density, which collectively contributed to higher yield. Since yield is governed by both fruit number and individual fruit weight, the simultaneous improvement in fruit retention (Table 1) and fruit growth (Table 3) resulted in a substantial increase in productivity. Similarly, the enhancement in fruit yield observed following NAA application may be attributed to its role as an auxin, which is known to counteract the effects of abscisic acid and ethylene responsible for fruit abscission (Ram, 1982) [21]. Furthermore, NAA may have contributed to maintaining hormonal balance, improving assimilate partitioning, and prolonging the active growth phase of developing fruits, thereby enhancing fruit growth and yield.

Although the performance of borax-treated trees remained comparatively lower than that of GA₃ and NAA, it was markedly superior to the untreated control. This is likely because boron primarily facilitates pollen viability, fertilization, carbohydrate transport, and cell wall development, whereas fruit enlargement and biomass accumulation are more directly regulated by endogenous growth hormones. Consequently, borax supported fruit development indirectly but could not match the pronounced effect of the plant bio-regulators on yield and yield-attributing traits. The present findings are aligned with those of Osama *et al.* (2015) [16] in mango; Maurya *et al.* (2020) [13] in mango and Nayak *et al.* (2024) [14] in litchi, who also documented significant improvements in fruit size, fruit weight, and yield following foliar application of plant growth regulators and micronutrient treatments.

Table 3: Effect of foliar spray of plant bio-regulators and micro-nutrients on the polar diameter, fruit weight, fruit volume and specific gravity of mango cv. 'Amrapali'.

Treatment	Polar diameter (cm)	Fruit weight (g)	Fruit volume (cm ³)	Specific gravity
T ₁ -GA ₃ 20 ppm	9.15	241	248.8	1.09
T ₂ -GA ₃ 40 ppm	8.46	228	211.6	1.06
T ₃ -GA ₃ 60 ppm	8.20	217	222.5	1.02
T ₄ -NAA 15 ppm	8.17	204	205.9	1.04
T ₅ -NAA 20 ppm	8.86	225	218.6	1.08
T ₆ -NAA 25 ppm	8.91	236	235	1.07
T ₇ -Borax 0.2 ppm	8.28	195	200	1.01
T ₈ -Borax 0.4 ppm	8.60	235	214.4	1.03
T ₉ -Borax 0.6 ppm	8.56	212	219.5	1.05
T ₁₀ -Control	7.95	188	189.4	0.9
SEm±	0.17	4.39	4.50	0.21
CD at 5%	0.52	13.50	13.39	0.63

Table 4: Effect of foliar spray of plant bio-regulators and micro-nutrients on fruit yield of mango cv. 'Amrapali'.

Treatment	Yield/tree(kg)	Yield(q/ha)
T ₁ -GA ₃ 20 ppm	16.7	288.8
T ₂ -GA ₃ 40 ppm	15.8	235.2
T ₃ -GA ₃ 60 ppm	12.6	259.2
T ₄ -NAA 15 ppm	12.0	252.8
T ₅ -NAA 20 ppm	14.7	241.6
T ₆ -NAA 25 ppm	16.2	267.2
T ₇ -Borax 0.2 ppm	11.6	201.6
T ₈ -Borax 0.4 ppm	14.3	192.0
T ₉ -Borax 0.6 ppm	15.1	185.6
T ₁₀ -Control	9.8	156.8
SEm±	0.2	4.6
CD at 5%	0.8	13.8

Conclusion

Among the evaluated treatments, foliar application of GA₃ at 20 ppm proved to be considered the most effective pre-harvest treatment for improving fruit yield and fruit quality of mango cv. 'Amrapali' under the agro-climatic conditions of eastern Uttar Pradesh, with NAA at 25 ppm serving as a promising alternative. Although borax application improved fruit growth and yield over the untreated control, its influence was comparatively less pronounced than that of GA₃ and NAA. Nevertheless, the positive response obtained with borax highlights the importance of adequate micronutrient nutrition in supporting reproductive development and fruit growth. However, further

investigations involving the combined application of plant bio-regulators with micronutrients, different application schedules and multi-location trials would be useful for developing more efficient and location-specific pre-harvest management strategies for mango production.

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