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RESEARCH ARTICLE

Role of nano-nutrients in enhancing the growth-regulating potential of paclobutrazol in guava cultivation under agro-climatic conditions of Punjab, India

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Abstract

Guava (*Psidium guajava* L.), a tropical fruit of nutritional and economic importance, often faces challenges such as excessive vegetative growth, uneven flowering and inefficient nutrient absorption. The present study, conducted in 2023-2024 at the Department of Fruit Science, School of Agriculture, Lovely Professional University, Phagwara, Punjab, evaluated the combined influence of paclobutrazol (PBZ) and nano-nutrients on growth regulation, physiological response, yield and fruit quality in guava cv. Allahabad Safeda. PBZ at 3.0 mL/L, a growth inhibitor was applied in conjunction with nano-boron (0.05 %) to assess their synergistic effects. The integrated application notably curtailed vegetative growth, as reflected by reduced plant height increment (0.45 cm), canopy volume (0.46 m^3) and stem girth (0.35 cm), suggesting a reallocation of assimilates toward reproductive development. Enhanced physiological parameters such as chlorophyll content, fruit firmness (5.81 kg/cm^2) and specific gravity (1.17) indicated improved plant efficiency. Significant gains were also recorded in fruit weight (187.54 g), length (6.68 cm), diameter (5.65 cm) and yield (26.05 kg/tree). These results highlight the effectiveness of combining PBZ with nano-nutrients in optimizing vegetative control, enhancing fruit quality and boosting yield. This integrated approach presents a sustainable strategy for improving guava production, particularly under resource-limited and variable agro-climatic conditions.

Keywords: canopy management; fruit quality; nano-nutrients; paclobutrazol; productivity

Introduction

Guava (*Psidium guajava* L.) is a member of the Myrtaceae family (1). It is regarded as one of the most splendid, nutritious and lucrative fruit crops, ranking fourth in terms of India's most significant fruit crop (2). Humans and other living things contributed to the dissemination of the guava (3). Guava fruit consumption lowers blood pressure, triglycerides and cholesterol. In addition, its fruit contains a lot of pectin, which lowers the risk of heart attacks (4). Guava fruits are highly cherished due to their richness in ascorbic acid, vitamin A and vitamin B (5). It is widely recognized for its medicinal value and has been extensively utilized in various traditional healthcare practices (6). Insufficient fruit consumption contributes to fatalities, especially in developing nations, while land degradation hampers agriculture (7). Smaller trees utilize sunlight more efficiently for fruit biomass production due to their greater surface area. Therefore, managing vegetative growth and minimizing canopy size is beneficial in tropical fruit orchards. Canopy management enhances fruit production and quality.

Paclobutrazol (PBZ) plays a crucial role in regulating excessive vegetative growth, promoting early and uniform flowering, controlling biennial bearing and supporting high-density plantations (8). As a potent soil drench, PBZ inhibits ent-kaurene oxidation, restricting gibberellin biosynthesis while increasing cytokinin levels, root activity and C:N ratio (2). By enhancing cytokinins and abscisic acid while reducing gibberellins, PBZ alters hormonal balance, leading to shorter internodes, reduced tree height and enhanced reproductive growth. Although PBZ is a relatively stable compound in soil environments, its variable influence on nutrient uptake may limit its overall nutritional efficacy; hence, the incorporation of nano-nutrients acts as a catalytic supplement to enhance nutrient assimilation and physiological efficiency.

Nano-fertilizers, known as "smart fertilizers,' enhance nutrient use efficiency while minimizing environmental impact and reducing protection costs (9). Encapsulated nanoparticles improve nutrient uptake, addressing long-term eutrophication by increasing utilization efficiency and mitigating macro- and micronutrient deficiencies (10). Zinc is crucial for protein, carbohydrate and enzyme synthesis, chlorophyll production and plant disease resistance, playing a key role in auxin synthesis (11). It is an essential micronutrient that plays a key role in carbohydrate metabolism, cell division and is a fundamental part of important enzymes such as carbonic-anhydrases (CA) and alcohol dehydrogenase and also contributes to improved photosynthesis and overall productivity (12). Calcium regulates enzyme activity, maintains membrane integrity and supports overall fruit quality (13). Boron (B) is vital for plant growth, influencing tissue differentiation, vegetative growth, membrane integrity, lignification, nitrate assimilation and nitrogen fixation (14).

Despite the individual benefits of PBZ and nano-nutrients, their combined application in guava remains largely unexamined under the unique agro-climatic conditions of Punjab, where high temperatures, varying soil fertility and fruit drop issues necessitate region-specific solutions. This gap highlights the novelty and practical relevance of the present study as it explored the integrated role of PBZ and nano nutrients in modulating growth dynamics and enhancing fruit productivity in guava.

Materials and Methods

Experimental site

The present study examined the impact of PBZ and nano-nutrients zinc, boron and calcium on the vegetative growth and fruit quality of guava (*Psidium guajava* L.) cv. Allahabad Safeda. The experiment was conducted in the Horticultural Orchard at Lovely Professional University, Phagwara, Punjab, India, from May 2024 to March 2025. The study coincided with the *mrig bahar* cropping season of guava, characterized by flowering during June -July and harvesting between November and January. The guava trees used in the experiment were 8-10 years old. In terms of geography, Lovely Professional University is situated at 31°13'28'' North latitude and 75°46'25'' East longitude, with an elevation of 245 meters above mean sea level (AMSL) and experiences a subtropical climate. According to the International Society of Soil Science (ISSS)-approved soil textural classification triangle, the soil of the experimental field may be classified as sandy loam.

Experimental design and treatment details

The experiment followed a two-factor randomized block design with four PBZ levels-P_0 (control) P_1 (1.5 mL/m canopy), P_2 (3 mL/ m canopy), P_3 (4.5 mL/m canopy) and four nano-nutrient levels-N_0 (control), N_1 (npCa at 2 %), N_2 (npB at 0.05 %), N_3 (npZn at 0.1 %). 8-10 year old guava trees were selected and 16 treatments were applied using PBZ in combination with nano-nutrients.

Paclobutrazol (PBZ) (Cultar 250 g/L SC, Syngenta) was applied as a soil drench at three concentrations: 1.5 mL (P_1), 3.0 mL (P_2) and 4.5 mL (P_3) per tree. Before application, light irrigation was provided to moisten the soil and enhance chemical absorption. Each tree received a 1 L drench of the PBZ solution, applied within a 25 cm-wide, 30 cm-deep circular ring dug 60 cm away from the trunk to target the active root zone. The required amount of PBZ for each treatment was freshly diluted in 1 L of water per tree: 1.5 mL PBZ in 1 L of water for P_1, 3.0 mL for P_2 and 4.5 mL for P_3. The formulation (250 g/L SC) contains 250 mg of active ingredient per mL and the doses were measured precisely using a micropipette or syringe.

Solutions were mixed thoroughly and applied using a calibrated plastic measuring jug to ensure uniform drenching. PBZ was applied as a soil drench during the early mrig bahar stage. The nano-nutrient formulations used in this study included nano-calcium (npCa), nano-boron (npB) and nano-zinc (npZn); all procured in powdered form. Each nano-nutrient was accurately weighed and dissolved in distilled water to prepare the required foliar spray solutions. A 2 % nano-calcium solution was prepared by dissolving 2 g of npCa powder in 100 mL of water (15). Similarly, a 0.05 % nano-boron solution was prepared by dissolving 0.05 g of npB powder in 100 mL of water and a 0.1 % nano-zinc solution was prepared by dissolving 0.1 g of npZn powder in 100 mL of water (16, 17). The solutions were freshly prepared prior to each application, thoroughly mixed to ensure uniform dispersion and applied using a hand-held sprayer during early morning or late afternoon hours to avoid evaporation and ensure optimal absorption.

Foliar applications of npZn, npCa and npB were carried out at 50 days intervals during initial, flowering and fruiting stages. Observations were recorded for plant height, stem girth, canopy volume, chlorophyll index, yield kg/tree, fruit weight, fruit length, fruit diameter, firmness and specific gravity. However, despite the evident benefits of nano-nutrients, it is important to consider potential risks associated with their use, such as environmental persistence and bio-accumulation, which are currently under investigation in global research. Careful management and application guidelines are necessary to harness their advantages while minimizing unintended ecological or health impacts.

Observations recorded

Plant height

Plant height was measured using a metallic measuring tape from the ground level to the topmost shoot tip of the tree. The increase in plant height was measured by subtracting the value of the initial measurement from the value of the final measurement and was expressed in cm.

Stem girth

Stem girth measurement was taken at 1.3 m above the ground using a Vernier caliper. The increase in stem girth was measured by subtracting the value of the initial measurement from the value of the final measurement and was expressed in cm.

Canopy volume

Canopy volume was measured using tree height and canopy spread. Height was recorded using a measuring tape, while canopy diameter was measured in two perpendicular directions to determine the radius. Canopy volume was calculated using the formula:

Canopy volume = 4/3 π a2 b

Where a = ½ of plant height and b = average of east-west and north-south spread (18). Percentage increase in canopy volume was measured:

[(Final volume - Initial volume) / Initial volume] × 100

with data recorded in triplicates.

Chlorophyll index

Chlorophyll index was measured using a Minolta SPAD-502 Plus chlorophyll meter. Readings were recorded from the youngest fully expanded leaves located at the top of the canopy to obtain SPAD (soil plant analysis development) values.

Fruit yields per plant

At the time of harvest, all the fruits from each replication were weighed on top pan balance and production was expressed kg per tree.

Fruit weight

Fruits from each treatment were selected randomly from the periphery of the tree and their weight was recorded with the help of top pan electrical balance and the weight was expressed in grams (g).

Fruit length

The size of the fruit was measured with Vernier caliper and expressed in cm.

Fruit diameter

Guava fruit diameter was measured using a Vernier caliper across its width and length, expressed in cm. The average was taken from multiple fruits.

Firmness

Fruit firmness was measured in terms of force (kg) required to penetrate the fruit pulp with Turoni (tr) penetrometer model GY-3. For this, a small portion of fruit was peeled out, the tip of a penetrometer was inserted into the peeled portion of fruit and the penetrometer reading was recorded and expressed in kg/cm^2.

Specific gravity

Specific gravity was determined according to water displacement method (19).

Statistical analysis

The recorded data were organized treatment-wise across three replications. One-way analysis of variance (ANOVA) was performed using IBM SPSS software (version 26; Chicago, IL, USA) to evaluate differences among treatment means. Duncan's multiple range test (DMRT) was employed for mean separation at a significance level of $p < 0.05$.

Results

Plant height increment

Plant height was significantly influenced by the application of PBZ and nano-nutrients. The minimum plant height increment (0.45 cm) was recorded with PBZ at 3 mL/m canopy (P_2), followed by P_3 (0.50 cm) as compared to P_0 (0.59 cm). Among nano-nutrients, npB at 40 ppm (N_2) retained the minimum plant height increment (0.45 cm) compared to N_0 (0.61 m) (Table 1).

Stem girth

The maximum increment in stem girth (0.46 cm) was observed under P_0, while the minimum increment (0.35 cm) was recorded with P_2. Similarly, npB at 0.05 % (N_2) record the lowest increment in stem girth (0.34 cm) compared to control (0.49 cm), presented in Table 1.

Canopy volume

Among different treatments, the minimum canopy volume (0.46 m^3) was recorded with P_2, followed by P_1, whereas the maximum increment was observed under control P_0 (0.63 m^3). Likewise, among nano-nutrients, the lowest canopy volume (0.41 m^3) was observed under npB at 0.05 % (N_2), while the highest canopy volume was observed under N_0 (0.69 m^3) as shown in (Table 1).

Chlorophyll index

P_2 exhibited maximum chlorophyll (45.97), followed by P_3 (42.96), compared to control P_0 (35.64). Similarly, among nano-nutrients, N_2 recorded the highest chlorophyll (46.59), as compared to control N_0 (34.86) as given in (Table 1).

Yield per tree

PBZ application at 3 mL/m canopy (P_2) produced maximum yield of fruits per tree (26 kg/tree), followed by P_1 (22.91 kg/tree) compared to the P_0(18.06). On the other hand, among nano-nutrient treatments, the highest yield (25.93 kg/tree) was observed with N_2, whereas the lowest (15.62 kg/tree) was found under N_0 (Table 1).

Fruit weight

Maximum fruit weight (187.54 g) was recorded with P_2, followed by P_3 as compared to P_0 (148.13 g) (Table 2). Similarly, among nano-nutrient treatments, N_2 recorded the highest fruit weight compared to N_0 (Fig. 1).

Table 1. Combined effect of paclobutrazol and nano-nutrients on growth parameters.

Treatments	Plant height (cm)	Stem girth (cm)	Canopy volume (m^3)	Chlorophyll index (SPAD)	Yield (kg/tree)
Factor A: paclobutrazol (P)					
P_0	0.59^a	0.46^a	0.63^a	35.64^d	18.06^d
P_1	0.53^b	0.42^b	0.53^b	40.92^c	22.91^b
P_2	0.45^c	0.35^c	0.46^c	45.97^a	26.05^a
P_3	0.50^b	0.40^b	0.57^b	42.96^b	21.87^c
SE(m)±	0.01	0.01	0.01	0.36	0.44
CD at 5 %	0.04	0.03	0.04	1.06	1.27
Factor B: nano-nutrients (N)					
N_0	0.61^a	0.49^a	0.69^a	34.86^d	15.62^d
N_1	0.50^b	0.38^b	0.50^c	43.17^b	24.71^b
N_2	0.45^c	0.34^c	0.41^d	46.59^a	25.93^a
N_3	0.51^b	0.41^b	0.59^b	40.86^c	22.63^c
SE(m)±	0.01	0.01	0.03	0.36	0.44
CD at 5 %	0.04	0.03	0.08	1.06	1.27
Interaction (P × N)					
SE(m) ±	0.04	0.83	0.03	0.73	0.88
CD at 5 %	0.07	2.42	0.08	2.11	2.54

P_0: control (no paclobutrazol), **P_1**: paclobutrazol at 1.5 mL/m canopy and **P_2**: paclobutrazol at 3 mL/m canopy; **P_3**: paclobutrazol at 4.5 mL/m canopy, **N_0**: control (no nutrient), **N_1**: npCa at 2 %, **N_2**: npB at 0.05 %, **N3**: npZn at 0.1%. Standard error of mean difference. CD at 5 %: critical difference at $p \leq 0.05$. Mean values labeled with the same letter were not significantly different at $p < 0.05$.

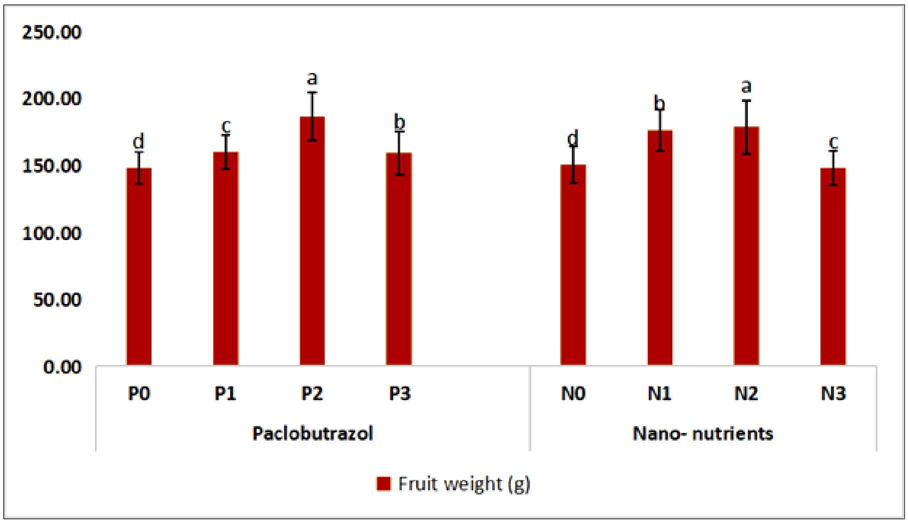

Fig. 1. Effect of paclobutrazol and nano-nutrients on fruit weight.

Fruit length

P_2, exhibited the maximum fruit length (6.68 cm), followed by P_1 (6.31), as compared to P_0 (5.25 cm) (Table 2). Similarly, N_2 exhibited maximum fruit length, whereas the lowest was observed in N_0 (Fig. 2).

Fruit diameter

The maximum fruit diameter (5.65 cm) was recorded with P_2, as compared to P_0 (5.01 cm) as shown in Fig. 3. Similarly, among nano-nutrients the highest fruit diameter was recorded with N_2 (Table 2).

Firmness

Among all treatments the maximum firmness (5.81 kg/cm^2) was recorded with P_2, while the minimum (5.08 kg/cm^2) was observed in P_0. Likewise, among nano-nutrient treatments, the highest fruit firmness (5.76 kg/cm^2) was recorded with N_1 (Table 2) whereas, the lowest (5.00 kg/cm^2) was recorded in N_0 (Fig. 4).

Specific gravity

Highest specific gravity (1.17) was recorded with P_2, which followed by P_3, compared to P_0 (Table 2). Similarly, among nano-nutrients N_2 recorded maximum specific gravity (Fig. 5).

Discussion

Plant height increment

The notable reduction in plant height with PBZ treatments is attributed to its role in inhibiting gibberellin biosynthesis, a hormone responsible for cell elongation and internodal expansion (20). By restricting gibberellin production, PBZ promotes compact plant growth with shorter internodes, thereby reducing the overall plant height (21). On the other hand, nano-boron treatment led to a comparatively lesser increase in plant height due to enhanced metabolic regulation and hormonal balance, particularly involving auxins and cytokinins, which modulate shoot elongation (22). Optimal boron supply strengthens cell wall structure and supports compact, sturdy growth, thereby limiting excessive elongation (23). In contrast, the control plants continued their natural gibberellin synthesis and elongation growth.

Stem girth

The reduction in stem girth under PBZ treatments may be due to suppression of cell elongation and division as a result of gibberellin inhibition, leading to compact and thickened tissues rather than

Table 2. Combined effect of paclobutrazol and nano-nutrients on fruiting parameters.

Treatments	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Fruit firmness	Fruit specific gravity
Factor A: paclobutrazol (P)					
P_0	148.13^d	5.25^c	5.01^c	5.08^d	1.02^d
P_1	160.15^c	6.31^{ab}	5.34^b	5.31^c	1.13^b
P_2	186.43^a	6.68^b	5.65^a	5.81^a	1.17^a
P_3	159.07^b	6.00^b	5.49^{ab}	5.46^b	1.08^c
SE(m)±	0.55	0.14	0.08	0.04	0.003
CD at 5 %	1.60	0.40	0.24	0.13	0.008
Factor B: nano-nutrients (N)					
N_0	150.79^d	5.09^c	4.77^c	5.00^d	0.98^d
N_1	176.12^b	6.31^{ab}	5.56^{ab}	5.76^a	1.14^b
N_2	178.52^a	6.65^a	5.70^a	5.38^c	1.16^a
N_3	148.34^c	6.20^b	5.45^b	5.53^b	1.11^c
SE(m)±	0.55	0.14	0.08	0.04	0.003
CD at 5 %	1.60	0.40	0.24	0.13	0.008
Interaction (P × N)					
SE(m) ±	1.10	0.28	0.16	0.09	0.006
CD at 5 %	3.19	0.80	0.47	0.25	0.017

P_0: control (no paclobutrazol), **P_1**: paclouburazol at 1.5 mL/m canopy and **P_2**: paclobutrazol at 3 mL/m canopy; **P_3**: paclobutrazol at 4.5 mL/m canopy, **N_0**: control (no nutrient), **N_1**: npCa at 2 %, **N_2**: npB at 0.05 %, **N3**: npZn at 0.1 %. Standard error of mean difference. CD at 5 %: critical difference at $p \leq 0.05$. Mean values labeled with the same letter were not significantly different at $p < 0.05$.

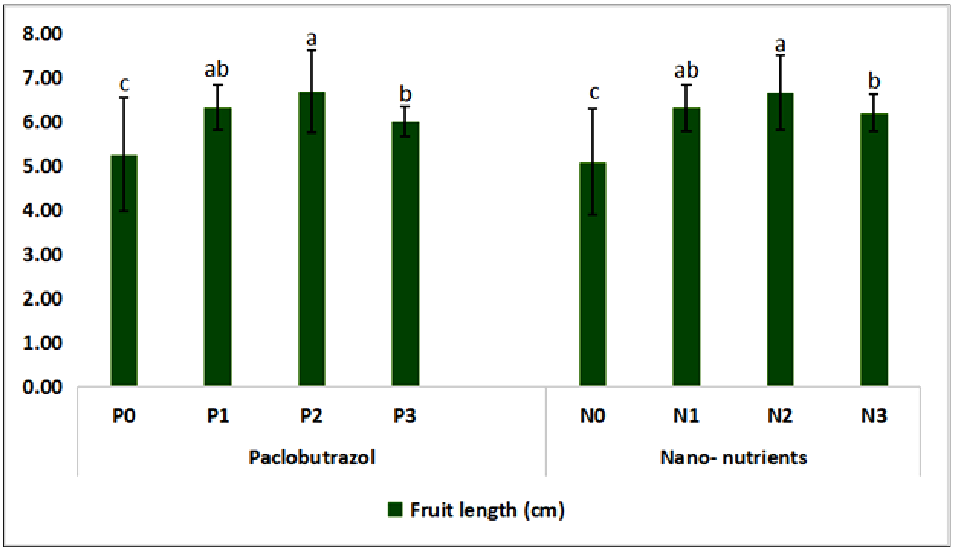

Fig. 2. Effect of paclobutrazol and nano-nutrients on fruit length.

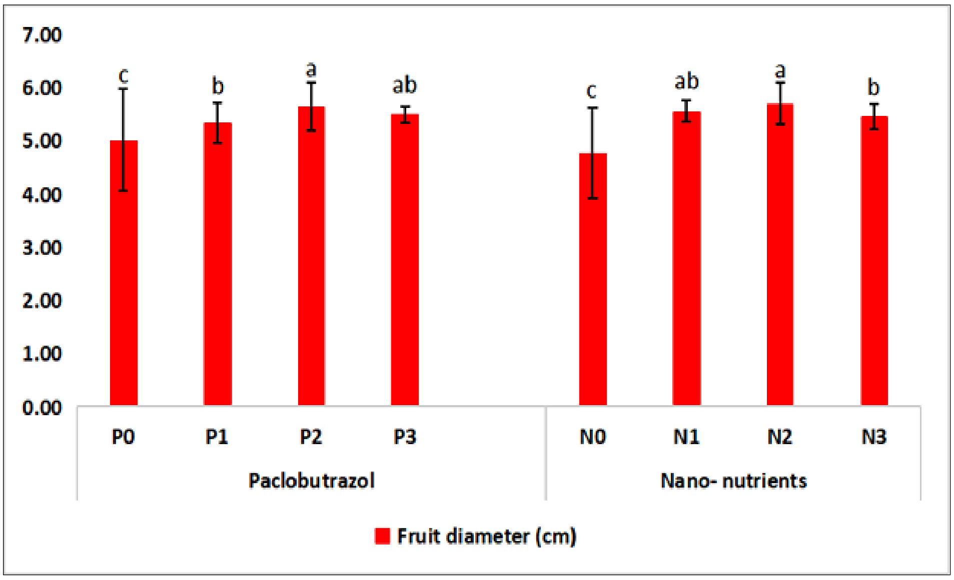

Fig. 3. Effect of paclobutrazol and nano-nutrients on fruit diameter.

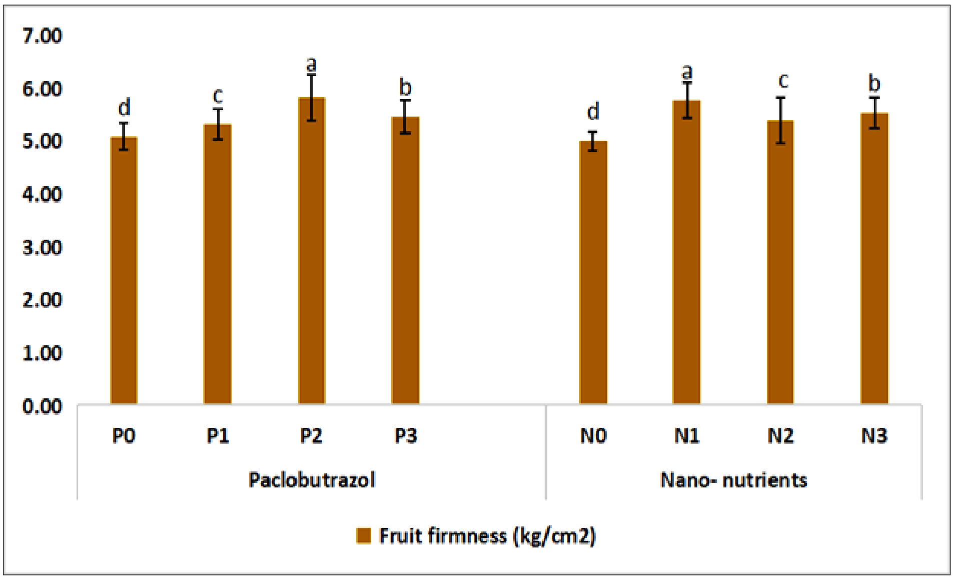

Fig. 4. Effect of paclobutrazol and nano-nutrients on fruit firmness.

elongation (24). Additionally, PBZ shifts the plant's resource allocation away from shoot elongation and vegetative growth, favoring the development of reproductive structures such as flowers and fruits instead (25). Nano-boron primarily contributes to this reduced increment by promoting physiological maturity and regulating plant growth, thereby restricting excessive secondary growth and channeling energy more efficiently toward fruit development (26).

Canopy volume

The reduction in canopy volume can be attributed to the growth-retardant action of PBZ, which restricts shoot elongation and leaf expansion by inhibiting gibberellin biosynthesis, resulting in compact canopy architecture (27). Nano-boron may enhance physiological maturity and reduce excessive vegetative growth, contributing to smaller, more efficient canopies with better light penetration (23).

Chlorophyll index

The increase in chlorophyll content under PBZ treatments is attributed to reduced vegetative growth, which allows greater nutrient allocation toward chlorophyll biosynthesis (28). Additionally, PBZ stabilizes chloroplast membranes and reduces chlorophyll degradation by minimizing oxidative stress, thereby enhancing chlorophyll retention and photosynthetic efficiency (29). On the other hand, boron enhances membrane integrity and the functioning of chloroplast enzymes, especially those involved in the synthesis of chlorophyll precursors like δ-aminolevulinic acid (ALA). The nano-formulation ensures better foliar penetration and mobility, thus promoting more efficient photosynthesis and greater pigment accumulation (30).

Yield per tree

The enhanced yield under PBZ treatment could be due to improved fruit set, reduced fruit drop and better assimilation allocation to reproductive structures (31). PBZ also helps synchronize flowering and fruit development, improving overall productivity (32). Similarly, boron plays an essential role in pollen tube growth, fertilization and fruit set, all of which directly influence fruit yield (33). The nano-sized boron allows for improved penetration and quicker response, contributing to enhanced fruit retention and development and thereby increasing the final yield (34).

Fruit weight

The increase in fruit weight due to PBZ application is attributed to enhanced assimilate partitioning toward developing fruits as a result of reduced vegetative growth (21). PBZ induces a compact canopy structure, which improves light penetration and reduces sink competition, thereby facilitating greater allocation of resources to individual fruits (35). Likewise, boron plays a crucial role in cell wall formation and sugar translocation, supporting improved cellular development and expansion in fruit tissues. The nano-formulation enhances nutrient uptake efficiency and internal mobility, promoting better fruit growth and increased fruit size (36).

Fruit length

The improved fruit length under PBZ treatments can be ascribed to enhanced metabolic efficiency and reduced vegetative competition, PBZ increases fruit length by inhibiting gibberellin synthesis, which limits shoot elongation and redirects assimilates to fruit (37). This enhances cell expansion and elongation in fruit tissues thereby PBZ-induced modulation of endogenous hormone levels establish a favorable auxin-to-cytokinin ratio, supporting sustained fruit elongation and development (38). Likewise, boron plays a vital role in meristematic activity and cell division during early fruit development by stabilizing cell wall structures and facilitating membrane integrity. It also supports sugar translocation and influences hormonal signaling pathways, both of which are essential for cell elongation and fruit growth (39). Its nano form likely ensured better absorption and utilization, leading to significant improvement in fruit length.

Fruit diameter

The enhancement in fruit diameter might be due to better translocation of assimilates to the developing fruit, reduced vegetative competition and enhanced sink strength under PBZ application (40). PBZ is known to redirect photo-assimilates from vegetative to reproductive structures (41). The enhancement in fruit size can be attributed to the increased rate of cell division, cell expansion and development of intercellular spaces influenced by the higher concentration of boron (42).

Firmness

PBZ likely improved firmness by enhancing dry matter accumulation and slowing the rate of cell wall degradation due to delayed ripening (25). It also promotes better textural stability of fruits by improving membrane integrity (43). Calcium plays a vital role in the synthesis of enzymes that strengthen cell walls and maintain fruit firmness, delaying senescence and enhancing postharvest quality (44).

Specific gravity

Increased specific gravity may be indicative of denser fruit tissues, possibly due to increased dry matter accumulation promoted by PBZ (45). Reduced vegetative sink demand under PBZ treatment could have led to improved allocation of assimilates to fruit, increasing its density (21). Likewise, boron's role in improving nutrient transport and cell wall synthesis could have contributed to higher dry matter content in fruits (39). Nano -boron enhances metabolic activity, particularly processes related to carbohydrate synthesis and accumulation in fruit tissues, leading to increased fruit density and consequently, higher specific gravity (46).

The interaction between PBZ and nano-nutrients ($P_2 \times N_2$) showed significant effects on multiple growth and yield parameters. Notably, the combination of PBZ at 3 mL/m canopy (P_2) with nano-boron at 0.05 % (N_2) consistently resulted in superior outcomes across key traits, including greater plant height increment, enhanced stem girth, larger canopy volume, higher chlorophyll index, improved fruit yield per tree and better fruit quality attributes. Fruit quality attributes include increased fruit weight, length, diameter and specific gravity. These synergistic effects may be attributed to the growth-retarding action of PBZ through gibberellin inhibition, coupled with nano-boron's role in improving metabolic efficiency, cell wall integrity and reproductive development. This highlights the potential of integrated use of growth regulators and nano-nutrients in optimizing guava productivity and quality.

Among the tested nano-nutrients, nano-boron (npB) proved most effective due to its key role in reproductive development and nutrient transport. Its nano form enhances absorption and mobility, ensuring efficient uptake and utilization. Compared to npZn and npCa, which support general metabolic and structural functions, npB directly influences plant growth and productivity. This justifies its selection as the most effective nano-nutrient in the study.

Environmental implications

PBZ is known for its high soil persistence due to strong adsorption and low mobility, which ensures prolonged efficacy but may lead to accumulation and potential disruption of soil microbial activity over time. Similarly, nano-boron enhances nutrient efficiency but, owing to its nano scale properties, may exhibit increased mobility and reactivity in the soil. While both are generally safe at recommended doses, their long-term environmental impacts and potential ecotoxicity warrant further investigation to ensure sustainable use.

Conclusion

The integrated use of PBZ and nano formulations led to marked improvements in plant height, stem girth, canopy volume, chlorophyll index, yield per tree, fruit weight, fruit length, fruit diameter, firmness and specific gravity. These results suggest that nano-nutrient supplementation can significantly boost the efficacy of PBZ, offering a viable approach to improving yield and fruit quality in guava cultivation. Continued exploration into precise application rates and the physiological basis of these effects will aid in refining sustainable production strategies for guava in comparable agro-regions. This investigation highlights the effectiveness of combining PBZ with nano-nutrients in enhancing growth regulation, yield and fruit quality of guava (Allahabad safeda) under Punjab's agro-climatic conditions. The integrated application of PBZ and nano formulations resulted in significant improvements in vegetative control, chlorophyll content, yield attributes and fruit physico-chemical characteristics. Notably, the combination of 3.0 mL PBZ per tree (P_2) with 0.05 % nano-boron (N_2) proved most effective, suggesting this dose as optimal for field application. The PBZ was applied as a soil drench during the early mrig bahar stage, while nano boron was sprayed during the pre-flowering phase, supporting better reproductive growth and nutrient translocation. These findings provide practical recommendations for farmers aiming to enhance guava productivity sustainably, while also encouraging further research on refining dosage and timing for varied agro-climatic conditions.

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Authors' contributions

HK carried out the field research trial and drafted the manuscript. RK prepared the design of the study. SS helped with the field trial and carried out the statistical analysis. All the authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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