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Research Article

Foliar application of nano-nutrients on the structural, photosynthetic traits and yield of *Psidium guajava* L.

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Background: A field experiment was conducted to study the effects of nano-macro and micronutrient formulations on growth, flowering, physiological attributes and yield of guava (*Psidium guajava* L.) var. Arka Kiran.

Method: The experiment utilized a Randomized Block Design featuring ten treatments, which included different quantities of zinc oxide (ZnO), boron trioxide (B_2O_3), calcium oxide (CaO), and magnesium oxide (MgO) nanoparticles foliar spray have been given to the guava (*Psidium guajava* L.) var. Arka Kiran**.**

Results: Demonstrated that ZnO nanoparticles at 1000 ppm (T_4) significantly enhanced on different stages of plant height (2.26 and 2.43 m), canopy spread (1.98 m NS 1.76 m EW and 2.27 m NS 1.92 m EW) during fruit development and harvesting stage, (23.89) days taken for flower initiation, (12.68) days taken from flowering to fruit set, (122.36) days taken from fruit set to maturity, (205.24) flowers per tree and chlorophyll on different stages (31.88, 43.43, 59.53 and 53.36) fruit set per cent (72.10) fruit retention per cent (48.98) number of fruits per tree (72.50) and estimated yield per tree (12.82) compared to other treatments and control.

Conclusion: The findings confirm the potential of nano-nutrient formulations, particularly ZnO nanoparticles in improving guava morphological characteristics, flowering characteristics and physiological health. These results provide a foundation for optimized nutrient management strategies in guava cultivation, promoting sustainable agricultural practices and enhancing productivity.

Keywords: *nanoparticles, macronutrients, micronutrients, growth, flowering, physiology, yield*

Introduction

Guava is a member of the Myrtaceae family and is categorized under the genus *Psidium*, which comprises approximately 150 species; however, only *Psidium guajava* L. has been commercially utilized. It is indigenous to Tropical America and was introduced to India in the 17th century by the Portuguese (Prakash et al., 2002). Guava is referred to as the "Apple of the Tropics" and the "Poor Man's Apple" (Rai et al., 2012). It is a delectable and nutritious fruit cultivated commercially across tropical and subtropical regions of India. The guava is rich in nutrients including iron, calcium, phosphorus, and vitamins such as ascorbic acid, pantothenic acid, and Vitamin A, as well as niacin (Embaby & Hassan, 2015). Nutrients are essential for the growth and development of plants, as well as for enhancing the quality of the produce. With an estimated production of 5.59 million metric tons in fiscal year 2023, India is not only a major guava producer but also the world leader, contributing a whopping 45% of global guava production. This impressive output is cultivated across 2.5 lakh hectares of land with Uttar Pradesh, Andhra Pradesh, West Bengal, Madhya Pradesh, and Gujarat leading in guava production (NHB 2024). Among the various factors, which affect the production and productivity of guava, macronutrient as well as micronutrients assumes great significance. Management of nutrients in guava refers to maintenance of the soil fertility and plant nutrient supply to an optimum level for sustaining the desired fruit quality through optimization of benefits from all the possible sources in integrated manner (Das, 2003). Guava is reported to develop characteristic deficiency symptoms in absence of N, P, K, Ca, Mg and S among macro-nutrients. Deficiencies of Zn, B, Mn, Fe, Cu, and Mo among micronutrients are also reported (Kumar, 2017). Inadequacy of either of these nutrients at critical stage of fruit development, adversely affect the productivity and quality of produce. According to Sau et al. (2017) foliar application of Zn, B and Cu increased the macronutrients (N, P and K) content in leaves of guava. Absorption of nutrients is high through the leaf's stomata compared to roots (Mondal et al., 2023). Micronutrients can be supplied more safely by foliar spraying, as plants require them in minimal quantities, allowing absorption through the leaf stomata and, in certain cases, through the cuticles. The absorption of nutrients by the leaf stomata is significantly more rapid than through the roots, making it the preferred way for providing plants (Bertolino et al., 2019). The production of high-quality fruit is increasingly challenging for the fruit trade to remain competitive in both home and international markets. The foliar application of micronutrients may represent a novel approach capable of yielding guava of unparalleled quality.

The farmers are use substantial quantities of fertilizers to enhance yield and production. Conventional fertilizers enhance crop output; nevertheless, their macronutrient use efficiency is notably low, with 50–70% of nutrients lost to the environment and not absorbed by plants (Marchiol, 2019). Thus, the fertilizers utilized for increased crop yield contaminate the environment and exhibit low economic efficiency (Ha et al., 2019). Nanotechnology possesses significant potential owing to its vast uses in agriculture and environmental sectors, attributed to its distinctive chemical and electrical properties (Qureshi et al., 2018; Chhipa, 2019). Nanotechnology possesses significant potential owing to its vast uses in agriculture and environmental sectors, attributable to its distinctive chemical and electrical properties (Qureshi et al., 2018; Chhipa, 2019). Nanotechnology transforms crystallites into nano-sized particles, enhancing their surface area and endowing them with notable transduction qualities, hence promoting sustainable agricultural output (León-Silva et al., 2018; Kopittke et al., 2019). Nano fertilizers are chemicals composed of nanoparticles that utilize nanotechnology to enhance nutrient utilization efficiency. Nano fertilizers are categorized into three classes: nanoscale fertilizers, nanoscale coatings, and nanoscale additives. The advantages of nano fertilizers encompass targeted release, controlled release, moisture retention, and rapid diffusion (Mikkelsen, 2018). The integration of nanoparticles with fertilizers leads to improved and efficient uptake of essential nutrients and compounds by plants, attributed to the high reactivity of nanomaterials (Prasad et al., 2017). We should explore alternative technologies, such as nanotechnology, to accurately detect and deliver the appropriate quantities of nutrients and other inputs necessary for crops, thereby enhancing productivity while ensuring environmental safety to tackle forthcoming challenges. Nanotechnology can enhance horticultural yield in production, processing, storage, packing, and transportation (Mousavi, 2011). Nanoparticles function as an effective delivery system due to their large surface area, sorption capabilities, and controlled-release kinetics aimed at specific sites. The extremely small size, enhanced specific surface area, and heightened reactivity of nanofertilizers may influence the solubility, diffusion, and ultimately the availability of nutrients to plants (Singh et al., 2013). This is where nanotechnology steps in offering a promising solution with the development of oxide nanoparticles. These engineered particles, specifically zinc oxide (ZnO), calcium oxide (CaO), magnesium oxide (MgO) and boron oxide (B_2O_3), hold immense potential for Indian guava cultivation. Their unique properties are due to their small size and large surface area. However, a standardized approach to Nano-micronutrients, specifically designed for Indian guava varieties, considering their impact on plant growth, yield and post-harvest shelf life is lacking. This research aims to address this gap by investigating the standardization of oxide nanoparticles of zinc, calcium, magnesium, and boron for guava. We will explore the effects of different Nano-micro and macronutrient formulations on plant growth parameters, fruit yield, and post-harvest shelf life. By establishing optimal application practices for Indian guava cultivation, this study seeks to contribute to developing sustainable and effective strategies. This research can benefit Indian guava farmers by enhancing production, quality, extending shelf life, leading to increased profitability and reduced fruit loss.

Materials and Methods

Study area

The experimental field was situated in Poongunam village, Cheyyur Taluk, Chengalpattu district, Tamil Nadu (12°21'North latitude and 79°52'East longitude, with an average elevation of 49 m). The experiment was conducted on five year old- guava var. Arka Kiran during rainy season crop. These trees were planted with a spacing of 2.5 m between rows and 3 m between plants in a rectangular system. The research aimed to standardize nano-macro and micro-nutrients for guava plant growth, flowering and physiological characters.

Experimental details

The experiment was laid out in Randomized Block Design (RBD) consist of ten treatments with three replications *viz*, T_1- Absolute control, T_2 - Control (Water), T_3 - Zinc Oxide NPs @ 500 ppm, T_4 - Zinc Oxide NPs @ 1000 ppm, T_5 - Boron Trioxide NPs @ 500 ppm, T_6 - Boron Trioxide NPs @ 1000 ppm, T_7 - Calcium Oxide NPs @ 500 ppm, T_8 - Calcium Oxide NPs @ 1000 ppm, T_9 - Magnesium Oxide NPs @ 500 ppm, T_{10} - Magnesium Oxide NPs @ 1000 ppm. Within each replicated block, the treatments were randomly assigned throughout the research field. The total number of trees in the experimental block was one hundred and fifty.

The above-mentioned nanoparticles are procured from Nano Research Lab, Jharkhand. The nutrients are supplied through foliar application and the nanoparticles are sonicated using a probe sonicator (100 W, 40 KHz, 50 amplitude) in deionized water for 30 minutes to form a homogenous solution, the trees received a thorough soaking with the spray solution via a Battery-Operated Knapsack sprayer, while the control group trees were sprayed with distilled water. The nutrients are applied in three stages for effective utilization by the plant. The stages are as follows I) pre-flowering stage (One month before flowering) II) fruit setting stage (45 days after first spraying - pea stage) and III) Fruit development stage (50 days after second spraying) respectively. The observations on morphology and physiological characters were recorded 30 days after imposing of each treatment (Siddik et al., 2016).

The observations on growth, flowering, physiological parameters and yield factors including tree height (m), canopy spread (m) (N-S and E-W) during the pre-flowering, fruit set, fruit development, and harvesting stages, as well as the duration for flower initiation, the interval from flowering to fruit set, the period from fruit set to maturity, the number of flowers per plant, and chlorophyll content.

The tree's height was measured from ground level to its top using a measuring tape and expressed in meters (m). Values of tree height were taken during the pre-flowering stage, fruit setting stage, fruit development stage and harvesting stage respectively. Canopy spread was measured in different directions viz., north-south and east-west. The number of days required for flower initiation, days taken from flower initiation to fruit setting stage, days taken from fruit setting to harvesting stage and number of flowers per plant was randomly recorded (4 shoots per tree in each direction) during the peak flowering period, and the average value was expressed in numbers.

The Minolta chlorophyll meter (SPAD, 502) was used to calculate the total chlorophyll in the fresh leaves. Using ten leaves from the fourth terminal expanded leaf of the shoot. Measurements were taken from the topmost fully developed leaf (four or five leaves from the apex). Plants had SPAD 502 readings during the first spray at the bud burst stage, 30 days later, and during harvest. To ascertain the mean SPAD values for each treatment, a total of forty SPAD readings were collected from plants.

Regarding yield characters, the fruit set percentage was calculated at the pea size stage and fruit retention was calculated at the time of harvest and expressed in percentage. The number of fruits harvested from each tree are recorded at the time of harvest and expressed in numbers. Fruits of each plant that were treated under research experimentation were weighed separately with top pan balance at each picking date and sum of all the pickings yield was worked out for assessing under different treatments.

Statistical analysis

The data underwent statistical analysis (Panse & Sukhatme 2000) using the AGRES software. Mean comparisons were conducted after computing analysis of variance (ANOVA), standard deviation (SE(d)) and least significant difference (LSD) values, with the critical difference set at a significance level of five per cent.

Results

Morphological characters

Application of different nano-macro and micronutrients through the foliar spray, data showed that there were non-significant of plant height and canopy spread during the initial and fruit setting stage. Further, it shows a statistically significant effect during the fruit development and harvesting stage on the plant morphological character of guava compared to the control as shown in (Table 1 & 2). The current research demonstrates that the utilization of nano-macro and micronutrients has markedly influenced the highest plant height at different stages *viz*, fruit development stage and finally harvesting stage (2.26 and 2.43 m) and canopy spread (1.98 m NS and 1.76 m EW during the fruit development stage and 2.27 m NS and 1.92 m EW at final harvesting stage) was observed under the Zinc oxide nanoparticles at 1000 ppm (T_4) followed by boron trioxide nanoparticles at 1000 ppm (T_6), which recorded the second highest plant height (2.19 m fruit development stage and 2.36 m harvesting stage) and canopy spread (1.61 NS and 1.72 m EW at fruit development stage, 1.83 NS and 1.84 m EW at harvesting stage). Conversely, the absolute control (T_1) had the lowest plant height (1.68, 1.81 m) and canopy spread (1.35 NS and 1.37 m EW at the fruit development stage, 1.41 NS and 1.60 m EW at the harvesting stage).

Table 1. Effect of foliar application of nano nutrients on plant height (m) characters at different stages of guava

Treatments	Pre-flowering Stage	Fruit setting stage	Fruit development stage	At harvest stage	Increase per cent (Pre-flowering to harvest)
T_1	1.57	1.58	1.68	1.81	15.29
T_2	1.59	1.62	1.79	1.92	20.75
T_3	1.65	1.79	1.87	2.01	21.82
T_4	1.74	1.88	2.26	2.43	39.66
T_5	1.70	1.91	2.07	2.23	31.18
T_6	1.79	1.95	2.19	2.36	31.84
T_7	1.80	1.90	2.17	2.33	29.44
T_8	1.81	1.92	2.06	2.22	22.65
T_9	1.88	1.93	2.02	2.17	15.43
T_{10}	1.90	1.96	2.12	2.28	20.00
S.E(Mean)	1.74	1.84	2.02	2.18	
SE(d)	0.11	0.13	0.13	0.07	
CD (0.05)	NS	NS	0.27	0.15	

Table 2. Effect of foliar application of nano nutrients on canopy spread (m) (NS and EW direction) characters at different stages of guava

Treatments	Pre-flowering stage		Fruit setting stage		Fruit development stage		At harvest stage		Increase per cent (Pre-flowering to harvest)	
	NS	EW	NS	EW	NS	EW	NS	EW	NS	EW
T_1	1.01	1.01	1.16	1.10	1.35	1.37	1.41	1.60	39.6	58.4
T_2	0.96	1.12	1.09	1.22	1.30	1.35	1.44	1.49	50.0	33.0
T_3	1.06	1.16	1.21	1.26	1.38	1.42	1.44	1.54	35.8	32.8
T_4	0.99	1.15	1.33	1.25	1.98	1.76	1.91	1.92	92.9	67.0
T_5	0.99	1.19	1.13	1.30	1.34	1.53	1.46	1.64	47.5	37.8
T_6	1.04	1.19	1.19	1.39	1.61	1.72	1.83	1.84	76.0	54.6
T_7	1.11	1.21	1.27	1.32	1.58	1.64	1.73	1.79	55.9	47.9
T_8	1.11	1.05	1.21	1.36	1.39	1.31	1.50	1.50	35.1	42.9
T_9	1.10	1.16	1.26	1.31	1.35	1.53	1.45	1.63	31.8	40.5
T_{10}	1.12	1.20	1.29	1.40	1.52	1.61	1.68	1.76	50.0	46.7
S.E(Mean)	1.05	1.16	1.21	1.29	1.48	1.52	1.59	1.67		
SE(d)	0.06	0.08	0.08	0.08	0.05	0.05	0.10	0.06		
CD (0.05)	NS	NS	NS	NS	0.10	0.11	0.21	0.12		

Flowering attributes

The experimental results regarding the flowering stage of the crop indicated significant variations in the application of zinc oxide nanoparticles concerning the days required for blooming, the duration from flowering to fruit set, the period from fruit set to maturity, and the number of flowers per plant across all treatments, as presented in Table 3. The results revealed that the application of nano zinc oxide nanoparticles (ZnO NPs) at 1000 ppm recorded the lesser duration required for guava flowering (23.89), days taken from blooming to fruit setting stage (12.68), duration required from fruit set to harvesting stage (122.36 days) and number of flowers per plant (205.24). However, control showed the maximum days for blooming (33.23), days taken from blooming to fruit set (16.52), days required from fruit set to maturity (144.55) and lesser amount of flowers per plant (167.71).

Table 3. Effect of foliar application of nano nutrients on flowering characters of guava

Treatments	No of days taken for flower initiation	No of days taken from flowering to fruit set	No of days taken from fruit set to maturity	Total number of flowers/tree
T_1	33.23	16.52	144.55	167.71
T_2	32.16	16.35	142.63	169.21
T_3	28.64	14.66	136.44	189.11
T_4	23.89	12.68	122.36	205.24
T_5	26.72	14.54	139.73	188.75
T_6	25.64	12.96	124.38	196.09
T_7	28.86	13.76	128.64	179.03
T_8	28.67	14.23	132.16	180.58
T_9	28.16	14.88	127.66	176.07
T_{10}	29.04	14.32	137.10	179.52
S.E(Mean)	1.36	0.16	1.72	2.32
SE(d)	1.92	0.22	0.16	3.28
CD (0.05)	4.05	0.48	5.13	6.89

Physiological parameters

Measurement with chlorophyll meter (SPAD 502)

The current study demonstrates that the application of nano, macro, and micronutrients significantly influenced the plant SPAD chlorophyll index, which was assessed at different spray durations and analyzed statistically, revealing a marked difference among treatments, consistent across different stages. The maximum SPAD value was recorded by Zinc Oxide Nanoparticles (ZnO NPs) at 1000 ppm for different stages (31.88, 43.43, 59.53 and 53.36 SPAD values, respectively). However, the minimum SPAD value was recorded in treatment control, with measurements of 30.56, 32.56, 35.80, and 34.10, respectively (Table 4).

Table 4. Effect of foliar application of nano nutrients on chlorophyll using SPAD value at different stages of guava

Treatments	Pre-flowering stage	Fruit setting stage	Fruit development stage	At harvest stage
T_1	30.56	32.56	35.80	34.1
T_2	30.41	36.56	41.14	38.33
T_3	31.65	36.15	45.19	42.3
T_4	31.88	43.43	59.53	53.36
T_5	30.65	39.30	50.01	42.03
T_6	30.74	42.23	57.46	52.33
T_7	31.23	39.36	51.23	48.23
T_8	32.01	40.24	47.09	41.17
T_9	31.01	39.56	49.51	43.54
T_{10}	30.11	38.66	50.10	48.12
S.E(Mean)	31.03	1.78	2.23	2.01
SE(d)	2.04	2.52	3.16	2.85
CD (0.05)	NS	5.30	6.65	5.97

Fruit and Yield parameters

The results about the effect of nano nutrients by foliar application on fruit set percentage showed a significant difference between treatments; the maximum fruit set percentage (72.10 per cent) was recorded by treatment (T_4) Zinc Oxide Nanoparticles (ZnO NPs) at 1000 ppm followed by the treatment (T_6) Boron Trioxide Nanoparticles (B_2O_3 NPs) at 1000 ppm (67.20 per cent). The lowest was recorded by the treatment (T_1) absolute control (48.33 percent) which is 23.77 per cent lesser than (T_4) treatment (Table 5). The maximum fruit retention percentage was recorded by treatment (T_4) Zinc Oxide Nanoparticles (ZnO NPs) at 1000 ppm (48.98 per cent), and it was statistically significant to all other treatments. This was followed by the treatment (T_6) Boron Trioxide Nanoparticles (B_2O_3 NPs) at 1000 ppm (46.99 per cent) and the lowest was recorded by the treatment (T_1) absolute control (36.02 per cent).

Upon a preliminary examination of the data, it was evident that nano-macro and micronutrients significantly influenced the number of fruits per tree, ranging from 29.20 to 72.50. Application of (T_4) Zinc Oxide Nanoparticles (ZnO NPs) at 1000 ppm resulted in the maximum amount of fruits per tree obtained with a total of 72.50 fruits per tree, followed by the treatment (T_6) Boron Trioxide Nanoparticles (B_2O_3 NPs) at 1000 ppm that recorded 61.93 fruits per tree. However, the treatment (T_1) absolute control had the lowest fruits per tree, 29.20.

Table 5. Effect of foliar application of nano nutrients on fruit and yield characters of guava

Treatments	Fruit set (%)	Fruit retention (%)	No. of fruits/tree	Estimated yield/tree (Kg)
T_1	48.33	36.02	29.20	4.07
T_2	49.43	37.74	31.57	4.42
T_3	59.08	46.63	52.10	8.30
T_4	72.10	48.98	72.50	12.82
T_5	58.78	46.23	51.30	7.95
T_6	67.20	46.99	61.93	10.28
T_7	53.56	41.53	39.88	5.65
T_8	50.92	43.14	39.67	5.87
T_9	51.28	40.42	36.50	5.16
T_{10}	49.87	42.90	38.43	5.68
S.E(Mean)	**56.06**	**43.06**	**45.31**	**7.02**
SE(d)	**3.81**	**2.89**	**3.24**	**0.52**
CD (0.05)	**7.79**	**5.91**	**6.62**	**1.06**

The foliar application of nano nutrients to guava trees significantly impacted the yield per tree (Table 5). Treatment (T_4) Zinc Oxide Nanoparticles (ZnO NPs) at 1000 ppm achieved the highest fruit output of 12.82 kg per tree, which was much better than all other treatments. Followed by (T_6), Boron Trioxide Nanoparticles (B_2O_3 NPs) at 1000 ppm recorded the second-highest fruit output of 10.28 kg per plant. In contrast, treatment (T_1) absolute control had the lowest fruit yield of 4.07 kg per plant

Discussion

The growth and development of trees result from the intricate coordination of various processes that occur during the growth phases of crop plants. The height of a plant and the girth of its stem are critical phenotypic traits that determine growth in terms of vigour, thereby directly impacting yield through the enhancement of canopy spread and the number of fruits produced. Therefore, comprehending the quantitative aspects of plant growth parameters is crucial for enhancing guava crop yield. Application of zinc oxide nano particles registered highest plant height and canopy spread in the present investigation. The application of ZnO nanoparticles improved the photosynthetic capacity of plants, hence augmenting cell division and resulting in increased plant biomass (Rai-Kalal & Jajoo, 2021). The above findings confirm that, the application of micronutrients through foliar spray increases the plant height and canopy spread in guava reported by (Bhoyar & Ramdevputra, 2017). Foliar application ZnO and FeO nanoparticles influence the maximum effect in increasing plant height and canopy spread on strawberries due to the application nano micronutrients, it may enhance the auxin biosynthesis through tryptophan-independent pathway resulting in increased height and canopy of plant (Singh et al., 2023). The application of zinc oxide nanoparticles (ZnO NPs) has led to an elevated production rate of gibberellic acid and indole acetic acid (IAA), potentially resulting in a decreased mean emergence time and an increased number of flowers and fruits per plant, which are critical factors for improved crop yield (Singh et al., 2023). The results indicate that the foliar administration of micronutrients in guava increased leaf count, decreased leaf abscission, and expedited flowering (Bhadarge & Singh, 2022). The results are partially aligned with the findings of Vani et al. (2020), Lenka et al. (2019), and Sahay et al. (2016) regarding Litchi; the increased growth of guava's terminal and lateral branches may have facilitated an enhancement in blooming and fruiting traits by promoting the development of a greater number of flower buds. These findings are consistent with Ali (2024) experiment on peach seedlings, Abd El et al. (2024) trial on pomegranate, Khanm et al., 2018 in tomato. The present study illustrates that the application of nano, macro, and micronutrients has substantially influenced the duration from flowering to fruit set and the maturation of fruit. The outcomes of this study align with the conclusions of Singh and Maurya (2004). These findings align with the data of Zagzog & Gad (2017) regarding mangoes and those of Kumar et al. (2017) concerning strawberries, suggesting abbreviated flowering durations. Early flowering is attributed to the efficient penetration of zinc oxide nanoparticles (Prasad et al., 2012), facilitated by an increase in leaf surface area and ion release via the cuticle (DaSilva et al., 2006). The increased chlorophyll content after foliar application of nano-zinc may be attributed to the activation of enzymes responsible for chlorophyll pigment production and its crucial function in facilitating cell division and differentiation, hence elevating chlorophyll levels (Mosa et al., 2021). In tomato plants, the application of ZnO-NPs resulted in substantial physiological changes, including increased chlorophyll and carotenoid concentrations, which are vital for flower development (Pejam et al., 2021). The application of zinc nanoparticles as a foliar spray markedly enhanced fruit set and fruit retention in the present investigation. The rudimentary influence of zinc nanoparticles on fruit retention may be associated with a reduction in fruit drop. Moreover, a connection exists between fruit drop and the endogenous hormonal status, alongside the presence of elevated internal auxin levels modulated by zinc, inhibiting fruit drop and enhancing guava fruit's retention rate. Zinc plays a crucial role in auxin synthesis, enhancing photosynthesis, increasing fruit starch accumulation, and a balanced auxin level in plants. This regulation affects fruit drop or retention, ultimately altering the control of fruit drop and increasing the total number of fruits per plant (Venu et al., 2014). The augmentation in the number of fruits per tree attributed to zinc application might originate from the influence of benzyl adenine, which promotes the generation of a substantial number of fruits alongside the swift elongation of the peduncle. This process facilitates the comprehensive maturation of flower buds, ensuring that all reproductive components are operational, thereby enhancing both the fruit set and the total count of berries per plant. The acceleration of differentiated inflorescence development may also be attributed to the application of zinc (Kumar et al., 2024). Using Zinc Oxide Nanoparticles (ZnO NPs) at a concentration of 1000 ppm yielded the highest fruit production. Plants subjected to zinc nanoparticles exhibited a notable enhancement in fruit yield. This seems to result from the prolonged availability of zinc, which facilitates various plant activities. Zinc may additionally play a role in the mobilization of other nutrients. Zinc administration in nanoparticle form may influence hormone levels, particularly auxin, facilitating enhanced growth, development and yield in plants. Sabir et al. (2014) and Kamiab & Zamanibahramabadi (2016) observed a yield increase attributed to zinc's application in its nanoparticle form. Comparable outcomes were noted by applying zinc oxide nanoparticles to foliage with higher concentrations of Zinc (Prasad et al., 2012).

Conclusion

The above results and discussion concluded that foliar application of (T_4) 1000 ppm zinc oxide nanoparticles (ZnO NPs) showed a significant response among all the treatments in guava resulting in the highest tree height, canopy spread, flowering characters, chlorophyll and yield characters followed by boron trioxide nanoparticles (B_2O_3 NPs) at 1000 ppm (T_6) over control. Nano-zinc oxide was key in enhancing nutrient absorption and plant growth, supporting previous research on nanoparticle efficacy in guava cultivation. Therefore, the foliar spray of 1000 ppm ZnO NPs can be recommended for maximum productivity on plant growth, flowering, physiological and yield attributes in guava.

Author contributions

Hameed Ali conducted research trial, collection, analysis of data, and manuscript writing. Ravanachandar Adhikesavan has contributed as a research guide, guided to conduct trials, observations, analyses & manuscript writing. Prakash Kasilingam contributed to the final version of the article. Chandrasekaran Perumal and Mohanasundaram Sugumar provided critical feedback and helped to shape the article.

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Competing Interests

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