



RESEARCH ARTICLE

Synergistic effects of humic acid, fulvic acid and chelated zinc and iron on growth, flowering and fruit quality of guava (*Psidium guajava* L.)

Somesh Sharma^{1*}, Jatinder Singh¹, Anis Mirza¹ & Amol Rajkumar Pawar²

¹Department of Horticulture (Fruit Science), Lovely professional university, Jalandhar 144 411, Punjab, India

²Department of Agronomy, Lovely professional university, Jalandhar 144 411, Punjab, India

*Correspondence email - attriatt@gmail.com

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Abstract

A field experiment was carried out at the Research Farm of the School of Agriculture, Lovely Professional University, Phagwara, Punjab, India, in the month of February to August 2024. The study examined how foliar sprays of humic acid (HA) at 0.25 %, fulvic acid (FA) at 0.17 % and chelated zinc (Zn) and iron (Fe) at 0.2 % and 0.4 %, applied individually and in various combinations, influence the growth, flowering and fruit quality of eight-year-old guava (*Psidium guajava* L.) cv. Allahabad Safeda. Sixteen treatments were arranged in a randomised complete block design (RCBD) with 3 replicates. Parameters measured included plant height, stem girth, chlorophyll content, number of flowers per shoot, fruit set, fruit retention, fruit weight, fruit length and fruit diameter. The most effective treatment was the combination of HA, FA, chelated Zn (0.2 %) and chelated Fe (0.4 %), which achieved the highest values across all parameters: plant height increased by 0.256 m, stem girth by 0.240 cm, chlorophyll content by 6.847 SPAD, flowers per shoot by 17.430 %, fruit set by 85.55 %, fruit retention by 84.01 %, fruit weight by 235.95 g, fruit length by 7.25 cm and fruit diameter by 7.01 cm. The control (water spray) registered the lowest values in all aspects. A strong positive correlation ($r > 0.92$) among all parameters suggested that improved vegetative growth directly supported better flowering and fruit quality. The study concludes that integrating biostimulants with chelated micronutrients offers an effective and straight forward foliar fertilisation approach for guava growers.

Keywords: biostimulants; chelated micronutrients; correlation; foliar application; plant parameters

Introduction

Guava (*Psidium guajava* L.) is one of the most important tropical fruit crops, often referred to as the “apple of the tropics” due to its wide adaptability and high nutritional value. It is a rich source of vitamin C, dietary fibre and antioxidants (1). India is the leading producer of guava, contributing approximately 5.45 million tonnes annually, accounting for nearly 46 % of global production (2). Major guava-growing states include Uttar Pradesh, Madhya Pradesh and Andhra Pradesh (3). Among these states, 195.6 thousand metric tonnes of production are estimated from Punjab (4). Owing to its nutritional and economic importance, guava is consumed fresh as well as processed into value-added products such as juices, jams and pulp, with increasing demand driven by rising health awareness (5).

Despite its significance, guava productivity and fruit quality remain suboptimal due to several constraints, particularly micronutrient deficiencies, poor flowering, heavy fruit drop and inferior fruit quality. These issues are often aggravated under intensive cultivation systems and calcareous or alkaline soils prevalent in subtropical regions like Punjab (3). Conventional soil application of nutrients is frequently inefficient due to nutrient fixation, leaching losses and antagonistic interactions, which limit nutrient availability during critical phenological stages (6).

Consequently, foliar nutrition has emerged as an effective strategy to bypass soil-related constraints, enabling rapid nutrient uptake and timely supply during flowering and fruit development (6, 7).

Recent advances in plant nutrition have highlighted the potential of chelated micronutrients and bio stimulants in improving crop performance. Chelated forms of zinc (Zn) and iron (Fe) exhibit greater stability, enhanced solubility and higher foliar absorption efficiency compared to their inorganic counterparts such as zinc sulphate (ZnSO_4) and ferrous sulphate (FeSO_4) (7, 8). Simultaneously, bio stimulants such as humic acid (HA) and fulvic acid (FA), derived from organic matter decomposition, play a crucial role in enhancing nutrient uptake, improving physiological efficiency and stimulating plant growth regulators (9, 10). These compounds are known to promote root proliferation, increase chlorophyll synthesis and enhance enzymatic and hormonal activities associated with flowering and fruit set (10, 11).

However, most existing studies have evaluated the individual effects of either micronutrients or bio stimulants, with limited emphasis on their integrated or synergistic application, particularly in guava under subtropical conditions. There is a lack of systematic research examining whether the combined foliar application of HA, FA and chelated micronutrients (Zn and Fe) can

produce additive or synergistic effects on growth, flowering behaviour and fruit quality. Furthermore, region-specific data for Punjab conditions are scarce, where soil characteristics and climatic variability may significantly influence treatment responses.

In this context, the present study was undertaken to evaluate the synergistic effects of HA, FA and chelated Zn and Fe on growth, flowering and fruit quality of guava under subtropical conditions of Punjab, India. The study aims to bridge the existing research gap by assessing whether integrated foliar applications of these inputs can enhance nutrient use efficiency and improve overall crop performance beyond their individual applications. It is hypothesised that the combined foliar application of HA, FA and chelated Zn and Fe will exert a synergistic effect, leading to significantly improved vegetative growth, enhanced flowering and fruit set and superior fruit quality in guava compared to their individual or conventional applications

Materials and Methods

Experimental site

The experiment was carried out at the Research Farm of the School of Agriculture, Lovely Professional University, Phagwara, Punjab, India, in the month of February to August 2024. The site is located at 31.24° N latitude and 75.70° E longitude at an elevation of about 252 m above sea level. The climate is semi-arid and subtropical with cold winters and hot summers. Annual rainfall is around 700–800 mm, mostly during July to September. During the trial, the maximum temperature was around 28 °C and the minimum dropped to about 10 °C in winter. The soil was sandy loam, moderately fertile, well-drained and slightly alkaline. Ambe bahar harvesting was done in the month of August 2024. Before the final harvesting, 4–5 pickings were done.

Soil conditions

The soil at the experimental site is classified as sandy loam to loam in texture, developed on Indo-Gangetic alluvial deposits. Before the experiment, composite soil samples were collected from 0–20 cm depth across the experimental area and analysed for physicochemical properties following standard procedures. The soil exhibited an alkaline reaction with a pH range of 7.8 to 8.3 (1 : 2 soil : water ratio) and an electrical conductivity below 0.8 dS m⁻¹, indicating non-saline conditions. Organic carbon content was low to medium, ranging from 0.35 % to 0.58 % (Walkley-Black method) (12). Available nitrogen (alkaline permanganate method) ranged from 180 to 240 kg ha⁻¹, available phosphorus (Olsen's method) (13) ranged from 12 to 18 kg ha⁻¹ and available potassium (ammonium acetate extraction) ranged from 180 to 220 kg ha⁻¹. The cation exchange capacity ranged from 3.5 to 5.0 cmol (p⁺) kg⁻¹. Micronutrient analysis revealed marginal deficiencies of Zn and Fe in some areas of the field, further justifying the need for foliar supplementation of these elements in the present study.

The experiment was laid out in a randomised complete block design (RCBD) with 3 replications. Each plot was 6 × 6 m and contained three uniformly grown eight-year-old guava plants of cv. Allahabad Safeda. Allahabad safeda is a medium to large and round shaped fruit. It has creamy white, soft and firm pulp. In total, 144 plants were selected based on their age and maturity. All plants received the same routine care, including irrigation, weeding and pest management throughout the study.

Experimental details

Treatment	Description
T ₀	Control (water spray)
T ₁	HA (0.25 %)
T ₂	FA (0.17 %)
T ₃	Chelated Zn (0.2 %)
T ₄	Chelated Zn (0.4 %)
T ₅	Chelated Fe (0.2 %)
T ₆	Chelated Fe (0.4 %)
T ₇	HA (0.25 %) + FA (0.17 %)
T ₈	HA (0.25 %) + FA (0.17 %) + Zn (0.2 %)
T ₉	HA (0.25 %) + FA (0.17 %) + Zn (0.4 %)
T ₁₀	HA (0.25 %) + FA (0.17 %) + Fe (0.2 %)
T ₁₁	HA (0.25 %) + FA (0.17 %) + Fe (0.4 %)
T ₁₂	HA (0.25 %) + FA (0.17 %) + Zn (0.2 %) + Fe (0.2 %)
T ₁₃	HA (0.25 %) + FA (0.17 %) + Zn (0.2 %) + Fe (0.4 %)
T ₁₄	HA (0.25 %) + FA (0.17 %) + Zn (0.4 %) + Fe (0.2 %)
T ₁₅	HA (0.25 %) + FA (0.17 %) + Zn (0.4 %) + Fe (0.4 %)

Zn: zinc; Fe: iron; HA: humic acid; FA: fulvic acid.

Sprays were applied three times (50 days interval):

First spray (Initial stage): 25 February 2024

Second spray (Flowering stage): 15 April 2024

Final third spray (Fruiting stage): 4 June 2024

To carry out the experiment, the HA was sourced from IFFCO, FA from Generic and Chelated Zn and Fe were obtained from Utkarsh. Spraying was done early in the morning using a hand sprayer to reduce evaporation. Humic acid per tree was applied in the concentration of 0.25 %. Fulvic acid was sprayed in the concentration of 0.17 %. Furthermore, the chelated Zn and Fe were applied in the concentration of 0.2 % and 0.4 % each per tree.

Observations

The following observations were recorded at 20, 70, 120 and 170 days (harvest) after the first spray:

Plant height increment (m)

Tree height was measured using a measuring tape placed 10 cm above ground level. Measurements were recorded before and after treatment application.

$$\text{Incremental plant height (P)} = P_2 - P_1$$

Where,

P₂ = final height

P₁ = initial height

Stem girth (cm)

It was measured by using tape, initially at a ring drawn with black paint along with trunk girth, followed by measurement of the circumference along trunk girth. The measurement was taken before and after the treatment application and the difference in the value was calculated.

$$\text{Incremental stem girth (SG)} = SG_2 - SG_1$$

Where,

SG₂ = final stem girth

SG₁ = initial stem girth

Chlorophyll content

Leaf chlorophyll content (SPAD) was measured using a SPAD-502 Plus meter. Readings were taken from four directions of the tree before and after treatment application.

Reproductive parameters

Number of flowers per shoot: Flowers were counted manually from selected branches in all 4 directions.

Fruit-set percentage: It was estimated by dividing the number of fruit set by the number of blooms that bloomed. It was expressed in percentage.

$$\text{Fruit set (\%)} = \frac{\text{Number of fruits}}{\text{Number of flowers}} \times 100$$

Fruit-retention percentage: Fruit retention was determined as the number of fruits retained till the maturity divided by the number of fruits set and was expressed as a percentage.

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

Fruit quality:

Fruit weight (g): The average weight of fruit was calculated after the final picking as per the formula given below:

$$\text{Average fruit weight} = \frac{\text{Total weight of fruits (g)}}{\text{Number of fruits}}$$

Fruit length (cm): Fruit length was measured for 10 selected fruits in each treatment with the help of vernier calipers and it is expressed as in cm.

Fruit diameter (cm): The diameter of 10 fruits was recorded at the widest portion with the help of Vernier calipers and expressed in centimeters.

The experimental data obtained were appropriately computed, tabulated and analysed by using MS-Excel and OPSTAT. Mean values of data were subjected to analysis of variance (ANOVA) as procedures outlined by previous researchers for RBCD. Critical differences were calculated at a 5 % level of significance. Pearson correlation coefficients were also calculated among all the parameters (15).

Results and Discussion

The present study clearly showed that when HA, FA, chelated Zn and chelated Fe were sprayed together on guava leaves, the plants performed much better than when any of these inputs were used alone. The best overall treatment was T₁₃ (HA + FA + Zn 0.2 % + Fe 0.4 %), which yielded the highest values for all measured parameters.

The enhanced vegetative growth in the combined treatments can be attributed to the complementary functions of the components. The HA and FA are known to activate root cell membrane enzymes like H⁺-ATPase, aiding in more efficient water and nutrient uptake (16, 17). These acids also stimulate the natural production of growth hormones such as auxins and cytokinin's, which promote cell division and elongation in shoots and stems (9, 10). Chelated Zn further supports this process by providing Zn, which is essential for synthesising tryptophan, the precursor of the major growth hormone IAA (18). Additionally, chelated Fe facilitates protein synthesis within chloroplasts, vital for photosynthesis (19). When all 4 elements are supplied together, the plant benefits from a steady supply of growth-promoting substances, explaining why T₁₃ exhibited the most vigorous growth. Previous studies have also reported similar growth improvements in guava when treated with HA (20).

Plant height

All treatments significantly increased plant height compared to the control at every observation point (Table 1). The greatest increase at 20 days after spraying was 0.256 m in T₁₃ (HA + FA + Zn 0.2 % + Fe 0.4 %), followed closely by T₁₅ (0.252 m) and T₁₄ (0.244 m), which were statistically similar to T₁₂ (0.242 m). Control plants showed the smallest growth with an increase of only 0.130 m. This pattern persisted at 70, 120 and 170 days. At harvest, T₁₃ and T₁₅ recorded the highest increases of 0.039 m, while the control only reached 0.021 m. Comparing individual treatments, HA alone (0.199 m) outperformed FA alone (0.191 m) and both were better than chelated Zn or Fe alone. The combination of HA and FA without micronutrients (T₇, 0.210 m) yielded better results than either alone; adding micronutrients to the bio stimulants further enhanced the response.

The pronounced increase in plant height under combined treatments may be attributed to the complementary action of HA, FA and chelated micronutrients in improving nutrient absorption and metabolic activity. Humic acid and FA stimulate membrane permeability, root activity and endogenous synthesis of growth-promoting hormones such as auxins and cytokinins, which enhance cell elongation and division (21). Zinc further supports auxin biosynthesis through its involvement in tryptophan metabolism, while Fe facilitates chloroplast development and enzymatic protein synthesis. Therefore, simultaneous application of these components ensured sustained vegetative vigour, resulting in the superior plant height observed in T₁₃. Similar enhancement in vegetative growth due to humic substances and foliar micronutrients has also been reported by earlier workers (22).

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

Treatment	20 Days	70 Days	120 Days	170 Days
Control (water spray)	0.130	0.060	0.030	0.021
Humic acid (0.25 %)	0.199	0.102	0.055	0.031
Fulvic acid (0.17 %)	0.191	0.097	0.053	0.030
Chelated Zn (0.2 %)	0.172	0.086	0.046	0.027
Chelated Zn (0.4 %)	0.176	0.088	0.047	0.028
Chelated Fe (0.2 %)	0.157	0.076	0.040	0.025
Chelated Fe (0.4 %)	0.165	0.080	0.043	0.026
HA + FA	0.210	0.108	0.060	0.033
HA + FA + Zn (0.2 %)	0.229	0.120	0.066	0.035
HA + FA + Zn (0.4 %)	0.230	0.120	0.066	0.035
HA + FA + Fe (0.2 %)	0.221	0.115	0.063	0.034
HA + FA + Fe (0.4 %)	0.222	0.116	0.064	0.034
HA + FA + Zn (0.2 %) + Fe (0.2 %)	0.242	0.128	0.071	0.037
HA + FA + Zn (0.2 %) + Fe (0.4 %)	0.256	0.137	0.077	0.039
HA + FA + Zn (0.4 %) + Fe (0.2 %)	0.244	0.130	0.072	0.038
HA + FA + Zn (0.4 %) + Fe (0.4 %)	0.252	0.135	0.075	0.039
C.D. (<i>p</i> ≤ 0.05)	0.007	0.004	0.003	0.001
SE(m)	0.002	0.002	0.001	0.000

HA: humic acid; FA: fulvic acid; Zn: zinc; Fe: iron.

Stem girth

Stem girth followed a similar trend (Table 2). After 20 days, the highest increase was 0.240 cm in T₁₃, with T₁₄ and T₁₅ close behind at 0.230 cm both comparable to T₁₂'s 0.227 cm. The control exhibited the smallest growth, at 0.120 cm. At harvest, T₁₃ again showed the greatest increment at 0.067 cm, compared to 0.030 cm in the control. Among individual treatments, HA (0.180 cm) outperformed FA (0.170 cm), which was better than chelated Zn at 0.2 % (0.150 cm). Chelated Fe at 0.2 % on its own yielded the lowest increase (0.130 cm), indicating that Fe alone, without bio stimulants, has a limited role in enhancing stem thickness.

Table 2. Effect of foliar application on stem girth increment (cm) of guava at different stages

Treatment	20 days	70 days	120 days	170 days
Control (water spray)	0.120	0.073	0.050	0.030
Humic acid (0.25 %)	0.180	0.107	0.073	0.050
Fulvic acid (0.17 %)	0.170	0.097	0.070	0.047
Chelated Zn (0.2 %)	0.150	0.090	0.063	0.040
Chelated Zn (0.4 %)	0.153	0.093	0.063	0.040
Chelated Fe (0.2 %)	0.130	0.073	0.053	0.033
Chelated Fe (0.4 %)	0.140	0.087	0.057	0.040
HA + FA	0.200	0.120	0.083	0.053
HA + FA + Zn (0.2 %)	0.217	0.130	0.090	0.060
HA + FA + Zn (0.4 %)	0.220	0.130	0.090	0.060
HA + FA + Fe (0.2 %)	0.207	0.123	0.087	0.057
HA + FA + Fe (0.4 %)	0.200	0.120	0.083	0.057
HA + FA + Zn (0.2 %) + Fe (0.2 %)	0.227	0.133	0.093	0.063
HA + FA + Zn (0.2 %) + Fe (0.4 %)	0.240	0.140	0.097	0.067
HA + FA + Zn (0.4 %) + Fe (0.2 %)	0.230	0.133	0.093	0.063
HA + FA + Zn (0.4 %) + Fe (0.4 %)	0.230	0.140	0.090	0.060
C.D. ($p \leq 0.05$)	0.016	0.011	0.008	0.007
SE(m)	0.005	0.004	0.003	0.002

HA: humic acid; FA: fulvic acid; Zn: zinc; Fe: iron.

Increase in stem girth under integrated foliar nutrition may be explained by improved cambial activity and better assimilate translocation resulting from enhanced nutrient availability. Humic substances improve water retention and nutrient transport, thereby maintaining continuous meristematic growth, while Zn and Fe activate several enzymes involved in carbohydrate metabolism and structural tissue development (23). The thicker stems obtained under T₁₃ indicate more robust vascular development and stronger sink-source connectivity, which is essential for supporting subsequent flowering and fruiting. A similar enhancement in structural growth and plant vigour under combined foliar micronutrient management in guava was also observed previously (22).

Chlorophyll content

Chlorophyll content measured as SPAD values showed significant differences among treatments at all stages (Table 3). At 20 days, T₁₃ recorded the highest value of 6.847, which was clearly better than all other treatments. T₁₅ (6.737) and T₁₄ (6.543) came next and these were at par with T₁₂ (6.480). The control recorded the lowest chlorophyll at 3.477. At harvest, values dropped in all treatments, as expected with leaf ageing, but T₁₃ still maintained the highest reading (1.037), compared to 0.530 in the control. Among individual treatments, HA alone (5.337) gave better chlorophyll content than FA (5.123) and both were considerably better than chelated Zn or Fe alone.

A significant increase in chlorophyll content with the combined treatments is crucial because chlorophyll drives photosynthesis. The Fe is essential for chlorophyll synthesis, as it is a component of enzymes in the protoporphyrin pathway (19). The higher chelated Fe dose (0.4 %) in T₁₃ probably ensured sufficient Fe for chlorophyll production. Zinc played a role in protecting chloroplast membranes from damage (18). Additionally, HA and FA boosted the activity of vital photosynthetic enzymes like Rubisco (9, 10). Increased chlorophyll levels led to enhanced photosynthesis, supplying the energy and sugars necessary for flowering and fruit development.

Table 3. Effect of foliar application on chlorophyll content (SPAD values) of guava at different stages

Treatment	20 days	70 days	120 days	170 days
Control (water spray)	3.477	1.910	0.973	0.530
Humic acid (0.25 %)	5.337	2.933	1.497	0.807
Fulvic acid (0.17 %)	5.123	2.813	1.437	0.773
Chelated Zn (0.2 %)	4.617	2.540	1.293	0.700
Chelated Zn (0.4 %)	4.713	2.593	1.320	0.713
Chelated Fe (0.2 %)	4.217	2.317	1.180	0.640
Chelated Fe (0.4 %)	4.407	2.423	1.233	0.667
HA + FA	5.623	3.090	1.573	0.850
HA + FA + Zn (0.2 %)	6.117	3.363	1.717	0.930
HA + FA + Zn (0.4 %)	6.150	3.383	1.727	0.933
HA + FA + Fe (0.2 %)	5.913	3.253	1.657	0.893
HA + FA + Fe (0.4 %)	5.947	3.270	1.667	0.900
HA + FA + Zn (0.2 %) + Fe (0.2 %)	6.480	3.560	1.817	0.983
HA + FA + Zn (0.2 %) + Fe (0.4 %)	6.847	3.767	1.920	1.037
HA + FA + Zn (0.4 %) + Fe (0.2 %)	6.543	3.597	1.833	0.990
HA + FA + Zn (0.4 %) + Fe (0.4 %)	6.737	3.707	1.887	1.020
C.D. ($p \leq 0.05$)	0.195	0.109	0.056	0.030
SE(m)	0.067	0.037	0.019	0.010

HA: humic acid; FA: fulvic acid; Zn: zinc; Fe: iron.

Flowers per shoot

The number of flowers produced per shoot was significantly affected by the treatments (Table 4). T₁₃ produced the most flowers (17.430 per shoot), which was at par with T₁₅ (17.367) and T₁₄ (17.000). T₁₂ also performed well with 16.960 flowers per shoot. In contrast, the control produced only 14.173 flowers per shoot, which was the lowest. Among single treatments, HA (15.067) was slightly better than FA (14.710), chelated Zn at 0.4 % (14.680) and chelated Fe at 0.4 % (14.610). The combination of HA + FA without micronutrients (T₇, 15.440) improved flowering compared to individual applications, but it was the four component combinations that really stood out.

Improved flowering in the integrated treatments suggests that foliar supply of bio stimulants and micronutrients positively regulated floral induction and differentiation. The rise in flower numbers is likely due to the hormonal effects of HA and FA, which stimulate cytokinin and gibberellin production to promote flower formation (9, 10). Zinc specifically supports pollen health and pollen tube growth, directly influencing successful fruit set (18, 24). Iron contributes energy to the reproductive process through its role in mitochondrial function (19).

Fruit set percentage

Fruit-set percentage showed the greatest differences among treatments (Table 4). T₁₃ achieved the highest fruit set of 85.55 %, which was significantly higher than that of all other treatments. T₁₅ (83.91 %) and T₁₄ (82.93 %) were at par with each other. T₁₂ also gave a high fruit set of 81.90 %. The control had only 59.95 % fruit set. Among single treatments, HA (71.34 %) was the best, followed by FA (69.21 %), chelated Zn at 0.4 % (67.65 %) and chelated Fe at 0.2 % (64.36 %). The gap between the best treatment (85.55 %) and the control (59.95 %) was about 25.6 % points, which is a very meaningful improvement from a farmer's perspective.

The substantial rise in fruit set under T₁₃ may be due to better pollen viability, successful fertilisation and reduced physiological stress at anthesis. Zinc is particularly important in pollen tube growth and fertilisation processes, while Fe supplies metabolic energy needed for reproductive development. In addition, HA and FA improve nutrient translocation and hormonal balance, reducing ovary abortion and enabling a higher proportion of flowers to convert into fruits.

Table 4. Effect of foliar application on reproductive parameters of guava

Treatment	Flowers/ shoot	Fruit set (%)	Fruit retention (%)
Control (water spray)	14.173	59.950	62.570
Humic acid (0.25 %)	15.067	71.343	70.550
Fulvic acid (0.17 %)	14.710	69.210	69.610
Chelated Zn (0.2 %)	14.633	66.857	68.957
Chelated Zn (0.4 %)	14.680	67.647	69.560
Chelated Fe (0.2 %)	14.587	64.357	64.910
Chelated Fe (0.4 %)	14.610	65.753	65.687
HA + FA	15.440	73.280	72.503
HA + FA + Zn (0.2 %)	15.863	78.343	76.533
HA + FA + Zn (0.4 %)	15.937	79.567	77.413
HA + FA + Fe (0.2 %)	15.823	75.047	74.907
HA + FA + Fe (0.4 %)	15.860	76.470	75.490
HA + FA + Zn (0.2 %) + Fe (0.2 %)	16.960	81.903	79.043
HA + FA + Zn (0.2 %) + Fe (0.4 %)	17.430	85.550	84.007
HA + FA + Zn (0.4 %) + Fe (0.2 %)	17.000	82.927	80.360
HA + FA + Zn (0.4 %) + Fe (0.4 %)	17.367	83.910	82.880
C.D. ($p \leq 0.05$)	0.924	2.257	2.704
SE(m)	0.318	0.778	0.932

HA: humic acid; FA: fulvic acid; Zn: zinc; Fe: iron.

Fruit retention percentage

Fruit retention followed the same trend as fruit set (Table 4). The highest retention of 84.01 % was observed in T₁₃, which was comparable to T₁₅ (82.88 %). These were followed by T₁₄ (80.36 %) and T₁₂ (79.04 %). The control had the lowest retention at 62.57 %. The difference between T₁₃ and the control was about 21.4 % points. This means that the combined treatment not only helped the plant set more fruits but also helped it retain those fruits until harvest, reducing premature fruit drop.

Higher fruit retention in combined treatments indicates improved hormonal equilibrium and continuous nutrient supply to developing fruits. The high fruit retention in T₁₃ (84.01 % versus 62.57 % in the control) is probably due to improved hormonal balance, especially adequate auxin levels at the fruit stalk junction, which prevents premature fruit drop (18, 25). These results align with previous studies show that combined micronutrient application reduces fruit drop in guava (24).

Fruit weight

Fruit weight data are presented in Table 5. T₁₃ produced the heaviest fruits (235.95 g), which were significantly heavier than those from all other treatments. T₁₅ (229.67 g), T₁₄ (227.82 g) and T₁₂ (226.60 g) were at par with each other. The control fruits weighed only 158.92 g. This means the best treatment increased fruit weight by about 77 g per fruit compared to the control, which is nearly a 48 % increase. Among single treatments, HA (193.05 g) was the most effective, followed by FA (187.07 g), chelated Zn at 0.4 % (176.72 g) and chelated Fe at 0.2 % (167.40 g).

The increase in fruit weight can be attributed to improved photosynthate production, nutrient translocation and enhanced cell expansion in developing fruits. The heavier and larger fruits in the combined treatments resulted from better cell division and cell expansion during fruit development. The HA and FA improved the movement of sugars from leaves to developing fruits, ensuring that more carbohydrates accumulated in each fruit (9, 26). Zinc activates enzymes like aldolase that are involved in sugar metabolism, while Fe supports the energy supply needed for active transport of sugars into the fruit (18, 19). Similar increases in fruit weight and size have been reported in guava with Zn and Fe foliar sprays (24) and in other fruit crops treated with humic substances (26, 27).

Table 5. Effect of foliar application on fruit quality parameters of guava

Treatment	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)
Control (water spray)	158.923	6.043	5.347
Humic acid (0.25 %)	193.053	6.733	6.163
Fulvic acid (0.17 %)	187.070	6.657	6.090
Chelated Zn (0.2 %)	174.910	6.527	5.980
Chelated Zn (0.4 %)	176.720	6.577	6.020
Chelated Fe (0.2 %)	167.397	6.373	5.780
Chelated Fe (0.4 %)	170.367	6.450	5.840
HA + FA	207.743	6.787	6.277
HA + FA + Zn (0.2 %)	215.267	6.957	6.517
HA + FA + Zn (0.4 %)	218.287	7.007	6.650
HA + FA + Fe (0.2 %)	209.453	6.893	6.340
HA + FA + Fe (0.4 %)	213.787	6.933	6.433
HA + FA + Zn (0.2 %) + Fe (0.2 %)	226.603	7.043	6.713
HA + FA + Zn (0.2 %) + Fe (0.4 %)	235.953	7.250	7.007
HA + FA + Zn (0.4 %) + Fe (0.2 %)	227.823	7.130	6.810
HA + FA + Zn (0.4 %) + Fe (0.4 %)	229.670	7.163	6.947
C.D. ($p \leq 0.05$)	16.980	0.085	0.078
SE(m)	5.851	0.029	0.027

HA: humic acid; FA: fulvic acid; Zn: zinc; Fe: iron.

Fruit length

The longest fruits (7.25 cm) were produced by T₁₃, followed by T₁₅ (7.16 cm) and T₁₄ (7.13 cm), which were at par (Table 5). T₁₂ (7.04 cm) was also significantly better than the remaining treatments. The control gave the shortest fruits (6.04 cm). Among individual treatments, HA (6.73 cm) and FA (6.66 cm) were better than chelated Zn or Fe alone.

The increase in fruit length under combined treatments indicates enhanced longitudinal cell division and enlargement during fruit growth. This is likely due to the cumulative effects of improved nutrient uptake, hormonal stimulation and greater carbohydrate availability provided by the integrated foliar spray. Similar significant enhancement in fruit length under combined foliar nutritional treatments in guava has also been reported by previous researchers (28, 29).

Fruit diameter

Fruit diameter showed a similar pattern (Table 5). T₁₃ recorded the widest fruits (7.01 cm), which were at par with T₁₅ (6.95 cm). T₁₄ (6.81 cm) and T₁₂ (6.71 cm) followed. The control had the smallest diameter (5.35 cm). The increase of about 1.66 cm in diameter from the control to the best treatment translates into noticeably larger, more marketable fruits.

Greater fruit diameter further confirms that the combined treatment promoted radial cell enlargement and better filling of fruit tissues. Improved photosynthetic efficiency and assimilate partitioning under integrated nutrition likely maintained active sink strength throughout fruit development, thereby producing bolder fruits with superior market appeal, which agrees with the findings of previous researchers, who reported that sustained carbohydrate accumulation and stronger sink strength are major determinants of fruit enlargement and final fruit mass (30). A similar increase in fruit diameter under combined foliar nutritional treatments in guava was also reported by earlier researchers, who observed maximum fruit diameter with integrated pre-harvest nutrient sprays compared to individual applications (28).

Correlation among parameters

The correlation matrix (Table 6) revealed that all parameters examined exhibited strong, positive relationships. Correlation

Table 6. Pearson correlation matrix among growth, flowering and fruit quality parameters of guava

Parameter	PH	SG	CHL	FL	FS	FR	FW	FLen	FD
PH	1.000	0.991**	0.999**	0.941**	0.990**	0.980**	0.991**	0.994**	0.987**
SG	0.991**	1.000	0.990**	0.930**	0.983**	0.970**	0.994**	0.976**	0.968**
CHL	0.999**	0.990**	1.000	0.941**	0.990**	0.980**	0.990**	0.994**	0.987**
FL	0.941**	0.930**	0.941**	1.000	0.970**	0.970**	0.952**	0.926**	0.953**
FS	0.990**	0.983**	0.990**	0.970**	1.000	0.991**	0.989**	0.984**	0.992**
FR	0.980**	0.970**	0.980**	0.970**	0.991**	1.000	0.977**	0.976**	0.989**
FW	0.991**	0.994**	0.990**	0.952**	0.989**	0.977**	1.000	0.975**	0.973**
FLen	0.994**	0.976**	0.994**	0.926**	0.984**	0.976**	0.975**	1.000	0.991**
FD	0.987**	0.968**	0.987**	0.953**	0.992**	0.989**	0.973**	0.991**	1.000

PH: plant height; SG: stem girth; CHL: chlorophyll; FL: flowers/shoot; FS: fruit set; FR: fruit retention; FW: fruit weight; FLen: fruit length; FD: fruit diameter. ** significant at $p \leq 0.01$.

coefficients ranged from 0.926 to 0.999. The highest correlations were observed between plant height and chlorophyll content ($r = 0.999$), fruit set and fruit diameter ($r = 0.992$), fruit set and fruit retention ($r = 0.991$), stem girth and fruit weight ($r = 0.994$) and fruit length and fruit diameter ($r = 0.991$). Even the weakest link, between flowers per shoot and fruit length ($r = 0.926$), was still highly significant. These robust positive correlations indicate that all parameters are interconnected.

The correlation analysis strongly supports these observations. All parameters were highly and positively correlated with each other ($r = 0.926$ – 0.999). This means that treatments that improved growth consistently and proportionally improved chlorophyll, flowering, fruit set and fruit quality. Such strong inter-parameter correlations confirm that the treatment effects were not random but followed a clear physiological chain: better nutrient uptake led to better growth, which led to more chlorophyll and photosynthesis, which supported more flowering and fruit set, ultimately resulting in bigger and heavier fruits in strawberries (31, 32).

Interaction effects

The results revealed a clear and significant interaction among the treatment components. The four-component combinations (T_{12} , T_{13} , T_{14} and T_{15}) consistently performed better than the three-component groups (T_8 to T_{11}), which in turn outperformed the two-component option (T_7) and the single applications. This progressive improvement with each additional component confirms that HA, FA, chelated Zn and chelated Fe act synergistically. Among the four-component treatments, T_{13} which has a lower Zn (0.2 %) and higher Fe (0.4 %) consistently produced the best results, indicating that this ratio was the most effective.

This synergistic superiority may be explained by the fact that HA and FA acted as natural nutrient mobilisers and absorption enhancers, while chelated Zn and Fe directly fulfilled micronutrient requirements involved in growth and reproductive metabolism. The lower Zn with relatively higher Fe concentration in T_{13} likely provided a more balanced micronutrient environment, avoiding possible Zn–Fe antagonism while maximising chlorophyll formation and metabolic efficiency. Hence, T_{13} emerged as the optimum integrated foliar treatment for guava under the present investigation.

An interesting finding was that HA consistently outperforms FA when used alone. This may be because HA has a higher molecular weight and can hold and release nutrients over a longer

period (9, 33). However, when combined, the two acids complement each other well because FA, being smaller, can penetrate leaf surfaces more easily and act more quickly (10, 34, 35). The chelated micronutrients were clearly more effective when combined with bio stimulants than when used alone, confirming that the organic acid environment created by humic and FA enhanced the plant's ability to absorb and use Zn and Fe more efficiently.

The relatively lower performance of chelated Fe alone (T_5 and T_6) compared to chelated Zn alone (T_3 and T_4) can be explained by the fact that Fe tends to get stuck in the leaf surface layer even in chelated form (17). But when HA and FA were added, they acted as natural chelators that kept Fe in a soluble and usable form for longer, which is why T_{13} with 0.4 % Fe performed better than T_{12} with 0.2 % Fe. On the other hand, the lower Zn dose (0.2 %) was sufficient to achieve full benefit, as higher doses can interfere with Fe absorption (26).

Conclusion

This study was carried out on eight-year-old guava cv. Allahabad Safeda at Lovely Professional University, Phagwara, Punjab, during 2023–24. It evaluated 16 foliar spray treatments using humic acid (HA), fulvic acid (FA), chelated zinc (Zn) and chelated iron (Fe), applied both individually and in combinations. The most effective treatment combined HA (15 mL/6 L), FA (10 mL/6 L), chelated Zn (0.2 %) and chelated Fe (0.4 %), resulting in the best overall parameters. This treatment led to the greatest increases in plant height, stem girth, chlorophyll content, number of flowers per shoot, fruit set, fruit retention, as well as the heaviest and largest fruits. Strong positive correlations among all parameters indicated interconnected and synergistic effects of the treatment. Based on these results, guava farmers are advised to apply this combined foliar spray every 50 days during the pre-flowering, flowering and fruit development stages to enhance growth, flowering and fruit quality.

These findings contribute to sustainable horticulture by reducing dependence on conventional fertilisers while improving yield and profitability. However, future research should focus on multi-location and multi-season validation, optimisation of nutrient doses and ratios, detailed physiological and molecular mechanisms, integration with biofertilisers or nano-inputs, economic feasibility analysis and assessment of post-harvest quality to strengthen and broaden the applicability of this approach across different crops and agro-climatic conditions.

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Authors' contributions

SS contributed to conceptualisation, formal analysis, investigation, methodology, statistical analysis, manuscript drafting and review and editing of the manuscript. ARP and JS contributed to data curation, investigation, methodology and preparation of the original draft. AM contributed to data curation, formal analysis, methodology, statistical analysis and review and editing of the manuscript. All authors read and approved the final manuscript.

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References

- Kumar M, Tomar M, Amarowicz R, Gupta V, Murthy PK, Singh B, et al. Guava (*Psidium guajava* L.) leaves: nutritional composition, phytochemical profile, and health-promoting bioactivities. *Foods*. 2021;10(4):752. <https://doi.org/10.3390/foods10040752>
- Gavhane NA, Patil SM, Shedge MS. Production and marketing of guava in India: an overview. *Int J Agric Sci*. 2022;14(2):45–52.
- National Horticulture Board. Indian Horticulture Database 2023–24. Ministry of Agriculture and Farmers Welfare, Government of India; 2025.
- Sahu K, Khunte SD, Chandrakar YK, Singh A. Advances in guava crop regulation: a review of recent research and developments. *Plant Arch*. 2025;25(1):557–64. <https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-1.075>
- Khan MA, Amir RM, Ameer K, Shahid M, Kiran M. Guava: a tropical fruit with diverse health benefits and industrial applications. *Food Sci Nutr*. 2024;12(1):1–18. <https://doi.org/10.1002/fsn3.3827>
- Patyal SK, Kumar R, Sharma M. Foliar nutrition in fruit crops: a review. *J Pharmacogn Phytochem*. 2024;13(1):108–14.
- Avdeeva VN, Kravchenko RV, Zhukov VD. Chelated micronutrient fertilisers: forms and application efficiency. *IOP Conf Ser Earth Environ Sci*. 2022;949:012034. <https://doi.org/10.1088/1755-1315/949/1/012034>
- Madhupriya B, Karthikeyan A, Senthilkumar M. Role of chelated micronutrients in horticultural crop production. *Pharma Innov J*. 2024;13(2):2190–5.
- Canellas LP, Olivares FL, Aguiar NO, Jones DL, Nebbioso A, Mazzei P, et al. Humic and fulvic acids as biostimulants in horticulture. *Sci Hortic*. 2015;196:15–27. <https://doi.org/10.1016/j.scienta.2015.09.013>
- Nardi S, Pizzeghello D, Muscolo A, Vianello A. Physiological effects of humic substances on higher plants. *Soil Biol Biochem*. 2002;34(11):1527–36. [https://doi.org/10.1016/S0038-0717\(02\)00174-8](https://doi.org/10.1016/S0038-0717(02)00174-8)
- Ahmed SS. Biostimulants in crop production: mechanisms and applications. *Front Plant Sci*. 2024;15:1287654.
- Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci*. 1934;37(1):29–38. <https://doi.org/10.1097/00010694-193401000-00003>
- Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No. 939. Washington DC: US Department of Agriculture; 1954.
- Usman S, Jayeoba JO, Ari MM, Amana SM. Research methodology: an agricultural perception. *Eurasian J Agric Res*. 2024;8(1):33–55.
- Felföldi Z, Ranga F, Roman IA, Sestras AF, Vodnar DC, Prohens J, et al. Analysis of physico-chemical and organoleptic fruit parameters relevant for tomato quality. *Agronomy*. 2022;12(5):1232. <https://doi.org/10.3390/agronomy12051232>
- Canellas LP, Olivares FL, Okorokova-Facanha AL, Facanha AR. Humic acids isolated from earthworm compost enhance root elongation, lateral root emergence, and plasma membrane H⁺-ATPase activity in maize roots. *Plant Physiol*. 2002;130(4):1951–7. <https://doi.org/10.1104/pp.007088>
- De Hita D, Fuentes M, Fernandez V, Zamarreno AM, Olaetxea M, Garcia-Mina JM. Humic substances: a valuable agronomic tool. *Water Sci Technol*. 2019;19(6):1735–40. <https://doi.org/10.2166/ws.2019.047>
- Bhoyar MG, Ramdevputra MV. Effect of foliar spray of zinc, iron and boron on growth, yield and sensory characters of guava cv. Sardar L-49. *J Appl Nat Sci*. 2016;8(2):701–4. <https://doi.org/10.31018/jans.v8i2.860>
- Rout GR, Sahoo S. Role of iron in plant growth and metabolism. *Rev Agric Sci*. 2015;3:1–24. <https://doi.org/10.7831/ras.3.1>
- Singh VK, Shukla AK, Singh AK. Synergistic action of humic acid substances and bio-inoculants in guava: impact on growth traits, fruiting, nutrient profiling. *J Plant Nutr*. 2023;46(4):661–80. <https://doi.org/10.1080/01904167.2022.2046069>
- Rathor P, Gorim LY, Thilakarathna MS. Plant physiological and molecular responses triggered by humic based biostimulants—a way forward to sustainable agriculture. *Plant Soil*. 2023;492(1):31–60. <https://doi.org/10.1007/s11104-023-06156-7>
- Bagal A, Sharma N, Bakshi P, Jamwal M, Jasrotia A, Kotwal N, et al. Improving growth and leaf nutrient content of guava (*Psidium guajava* L.) with micronutrient management. *Int J Adv Biochem Res*. 2025;9(1S):1033–6. <https://doi.org/10.33545/26174693.2025.v9.i1Sn.3668>
- Maffia A, Oliva M, Marra F, Mallamaci C, Nardi S, Muscolo A. Humic substances: bridging ecology and agriculture for a greener future. *Agronomy*. 2025;15(2):410.
- Pippal R, Lekhi R, Barholia AK, Rana S, Rana P. Response of guava to foliar spray of zinc, boron and magnesium on growth, development and yield. *J Pharmacogn Phytochem*. 2019;8(2S):524–8.
- Balakrishnan K. Foliar spray of zinc, iron, boron and magnesium on vegetative growth, yield and quality of guava. *Ann Plant Physiol*. 2000;14(2):151–3.
- Li Y, Fang F, Wei JL, Wu XB, Cui RZ, Li GS, et al. The positive effects of humic/fulvic acid fertilizers on the quality of lemon fruits. *Agronomy*. 2022;12(8):1919. <https://doi.org/10.3390/agronomy12081919>
- Mosa WFA, Sas-Paszat L, Gluszek S, Panczyk M, Abou El-Nasr NA. Vegetative growth, yield and fruit quality of guava cv. Maamoura as affected by some biostimulants. *BioResources*. 2021;16(4):7542–58. <https://doi.org/10.15376/biores.16.4.7542-7558>
- Mavinalli SY, Shinde VN, Adsul PB, Sarvade PB, Gavhane YD, Ritthe RD. Studies on pre-harvest spray of plant growth regulators and nutrients to improve the quality of guava (*Psidium guajava* L.) cv. Sardar. <https://doi.org/10.33545/26174693.2024.v8.i10Sq.2735>

29. Meena S, Kumar S, Meena RK, Divaker N, Meena K, Meena R. Impact of foliar spray of micronutrients and plant growth regulators on growth and yield of guava (*Psidium guajava* L.) cv. L-49. *Int J Environ Agric Biotechnol*. 2024;9(6):36–39. <https://doi.org/10.22161/ijeab.96.6>
30. Nakai H, Yasutake D, Hidaka K, Miyoshi Y, Eguchi T, Yokoyama G, et al. Sink strength dynamics based on potential growth and carbohydrate accumulation in strawberry fruit. *HortScience*. 2024;59(10):1505–10. <https://doi.org/10.21273/HORTSCI18013-24>
31. Zebro M, Baek JH, Kim M, Jeong Y, Rabbani MG, Choi KY. Nutrient solution strength affects growth, physiology, biochemistry and fruit quality of Korean strawberry 'Kuemsil' in a recycling hydroponic system. *Front Plant Sci*. 2025;16:1685755. <https://doi.org/10.3389/fpls.2025.1685755>
32. Choi HG. Correlation among phenotypic parameters related to the growth and photosynthesis of strawberry (*Fragaria × ananassa* Duch.) grown under various light intensity conditions. *Front Plant Sci*. 2021;12:647585. <https://doi.org/10.3389/fpls.2021.647585>
33. Chaab A, Savaghebi GR, Motesarezadeh B. Differences in the zinc efficiency among and within maize cultivars in a calcareous soil. *Asian J Agric Sci*. 2011;3(1):26–31.
34. Bezerra-Neto E, Mendes LW, Lopes CM, Figueiredo MVB. Humic foliar application as sustainable technology for improving growth, yield, and abiotic stress protection of agricultural crops. *Saudi J Biol Sci*. 2023;30(6):103672. <https://doi.org/10.1016/j.sjbs.2023.103672>
35. Haggag LF, Fawzi MI, Shahin MFM, El-Hady ES. Effect of yeast, humic acid, fulvic acid, citric acid, potassium citrate and chelated micro-elements on yield, fruit quality and leaf minerals of Canino apricot. *Int J ChemTech Res*. 2016;9(4):7–15.

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