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Effect of foliar application of plant growth regulators and micronutrients on quality of acid lime (*Citrus aurantifolia* Swingle) Cv. Balaji

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Abstract
The present investigation entitled "Effect of foliar application of plant growth regulators and micronutrients on yield and quality of acid lime (*Citrus aurantifolia* Swingle) cv. Balaji" was carried out during the year 2021-2022 at farmer field, Banda Timmapur (village), Konda Mallepally, Nalgonda (Dist). The experiment was laid out in Randomized Block Design (RBD) with eight treatments and three replications. The results indicate that the acid lime tree sprayed with GA_3 (50 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$(0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%)**,** recorded maximum increase in juice percent (49.15%) and shelf life (23.70%) and Quality attributing characters like total soluble solids (7.50 ^{0}Brix), total sugars(1.88%), reducing sugars (0.92%), non-reducing sugars (0.94%), titrable acidity (7.89%) and ascorbic acid (30.15 mg/100 g) were found to be maximum with the foliar application of NAA (100 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%). while minimum was recorded in Control (water spray).

Keywords: PGR's, micronutrients, quality, shelf life, acid lime

Introduction
Acid lime (*Citrus aurantifolia* Swingle) is the third-most significant fruit crop within the citrus family next to mandarin and sweet orange. It is commonly cultivated in India's tropical and subtropical regions. It belongs to the family Rutaceae and has a chromosome number (2n=18). It is a highly priced and economically remunerative fruit. Due to their distinctive flavours and medicinal properties, citrus fruits are particularly significant. It has excellent antioxidant effects and is a good source of vitamin "C". India is the world's largest producer of acid lime with an area of 3,22,000 Ha and a production of 35,17,000 MT (NHB 2021-22) [15]. It is largely cultivated in Andhra Pradesh, Telangana, Karnataka, Odisha, Madhya Pradesh, Maharashtra, Assam, Bihar, Chhattisgarh, Manipur, Jharkhand, Tamil Nadu, Tripura and Mizoram. The major acid lime growing districts in Telangana are Nalgonda, Suryapet, Gadwal, Mahabubnagar and Ranga Reddy Acid lime is used to make candies, chocolate, ice cream, pastries, and 100 grams of fruit juice include 80% water, 26 IU of beta-carotene, 20 mg of vitamin A, 0.1 mg of riboflavin, 63 mg of vitamin C, 1.83 mg of iron, and 0.16 mg of copper. Because it contains oxalo-acetic acid (0.30%), malic acid, and alkaline salt (8.2%), it is important for human health. It consists of 6.3-6.6 percent citric acid. The acid lime fruits are used for making pickles and refreshing drinks as well as for manufacturing syrup and squash. It acts as an appetizer, antiscorbutic, antihelmintic and checks biliousness besides a good source of nutrients, vitamins and other antioxidant compounds (Chadha, 2002) [6]. Acid lime trees flowers three times a year in the months of January-February, June-July and September-October are known as Ambia, Mrig and Hasta bahar, respectively. The months of June-July, November-December, and April-May, respectively, see the fruits of the flowering of the Ambia, Mrig, and Hasta bahar. The flowering percentage of Ambia, Mrig and Hasta bahar arise at 47%, 36% and 17% respectively. India's citrus orchards are facing with problems pertaining to fruit size, colour, and quality, as well as an excessive amount of premature fruit drop. When used as plant growth regulators, 2,4-D is essential for preventing pre-harvest fruit drop, which eventually increases yield without affecting fruit quality. NAA promotes fruit retention, increases fruit weight, and checks pre-harvest fruit drop. It also increases fruit TSS and weight. GA_3 increases fruit weight, fruit diameter, and length, which increases yield (Shinde *et al.*, 2008) [19]. Micronutrient deficiencies (Zn, Cu, Fe, Mn, Mg, and boron) in the soil of citrus orchard also have an impact on fruit productivity, quality, and fruit drop (Ibrahim

et al., 2007 [10] and Ashraf *et al.*, 2012) [3]. The citrus orchards have long been noted to have severe zinc deficiencies. Zinc is crucial for fruit quality, fruit production, fruit growth, and flowering. Zinc also essential for the growth and development of fruits and enhances the chlorophyll content of leaves. As a result of iron enhancing photosynthesis and carbohydrate synthesis in the leaves, flowering, fruit set, fruit size, and fruit drop are all increased. The growth of viable seeds and pollination are both impacted by boron, which also has an impact on how fruit normally grows. Manganese is essential for photosynthesis, respiration, nitrate assimilation, the production of chlorophyll, and the activity of several enzymes. Micronutrients can significantly increase the productivity and quality of horticultural crops. Application of micronutrients through foliar spray is crucial for flowering and the production of high-quality fruit. The present study was therefore undertaken to investigate the effect of foliar application of plant growth regulators and micronutrients on yield and quality of acid lime cv. balaji., which may helps in increasing the yield and quality of the fruit.

Material and Methods

A field experiment was planned on 20 year old acid lime trees at farmer field, Banda Timmapur (village), Konda Mallepally, Nalgonda district during the year 2021-2022. The experimental site is situated at a latitude of 17º.32' North, longitude of 78º.40' East and altitude of 224 m above mean sea level (MSL). The experiment was laid out in Randomized Block Design (RBD) with eight treatments and three replications. There were two spray schedules *i.e.*, 1st spray 2nd week of march at petal fall stage and 2nd spray 45 days after 1st spray. Two trees were taken for each treatments. The orchard was laid out by adopting square system with a spacing of 7m x 7m. The required dose of manures, fertilizers, irrigation and plant protection measures were given to each selected tree. Treatments consisted of T_1: 2,4-D (10 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%), T_2: 2,4-D (20 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%), T_3: GA_3 (25 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%), T_4: GA_3 (50 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%), T_5: NAA (50 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%), T_6: NAA (100 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%), T_7: $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%), T_8: Control (Water spray). Number of fruits per plant and yield per tree were counted manually during harvesting. The juice from fruit was extracted by lemon squeezer. The percentage of juice contain was calculated in relation to weight of the fruit from each treatment. Total soluble solids (T.S.S) of ripe fruit pulp was recorded by digital pocket hand refractometer (ranging from (0-32 ºBrix). Drop of extracted acid lime juice was put on hand refractometer and reading was recorded and expressed in terms of degree brix. Six readings were taken for each treatment and finally their average value was worked out. Care was also taken to clean the prism with distilled water and dry it before taking next reading. The titrable acidity of the juice was determined according to the method given in for this, 10ml of juice was titrated against 0.1 N NaOH solution using phenolphthalein as an indicator. The percent acidity was calculated by using following formula.

Acidity (%) = 0.064 x Burette reading.

Ascorbic acid content was estimated by the procedure described by Ranganna (1979) [18] by using 2, 6 dichlorophenol dye as an oxidizing agent for titration. The ascorbic acid content of the juice was estimated on fresh weight basis and expressed as mg/100 ml juice of fruit. The ascorbic acid content less than 100 mg /100 ml pulp was termed as fair, those between 100 to 200 mg as good and those above 200 mg as high. The reducing sugar from juice was estimated as per the method described by Ranganna (1979) [18] and expressed in percentage. Fifty ml composite juice sample of the same kind of juice was taken and precipitated by using 2 ml neutral lead acetate (45%). After 10 minutes, 1.8 ml of potassium oxalate (22%) was added to delead the sample solution and then the final volume was made upto 250 ml. After filtration, the filtrate was used for estimating reducing sugar by titrating it against Fehling solution (Fehling A and B in 1 : 1 proportion) at boiling temperature with an end point as brick red by using methyl blue as an indicator.

$$\text{Reducing sugar (\%)} = \frac{50}{\text{Burette reading}} \times 100$$

It was calculated by subtracting the value of the reducing sugar from total sugar of the juice from each sample separately. Total sugar was estimated by the same method as that of reducing sugar. For this, 50 ml clean filtrate was taken in 50 ml volumetric flask and 5 ml of 35 percent hydrochloric acid (HCL) was added to it. This was hydrolysed for half an hour in hot water bath. After hydrolyzing, the excess acid was neutralized by sodium carbonate (40%) and the volume was made to 250 ml. It was then titrated against 5 ml each of Fehling A and Fehling B solutions using methyl blue as an indicator.

$$\text{Total sugar (\%)} = \frac{\text{250 ml}}{\text{Burette reading}} \times 100$$

Results and Discussion Quality Parameters

1. Total soluble solids (ºBrix)

The data pertaining to TSS as influenced by various plant growth regulators and micronutrients of acid lime is presented in Table 1. Significant difference was noticed in the total soluble solids with foliar application of growth regulators and micronutrients on acid lime. The maximum amount of total soluble solids (7.50 ºBrix) was found in the treatment T_6– NAA (100 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + MnSO4 (0.2%) + Boron (0.1%) followed by T_5 - NAA-50 ppm + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%) (7.26 ºBrix), which are on par respectively. However, the minimum level of total soluble solids (6.50 ºBrix) was found in the treatment T_8 - Control. The quick transfer of sugar from leaves to developing fruits and the production of cell wall material were the reason of the boron increases in TSS (Ali *et al*. 2014) [1]. These results are in correspondence with the findings of Ebeed *et al*. (2001) [9] in mango, Singh *et al*. (2007) [20] in citrus orchards, Nawaz *et al*. (2008) [16] in kinnow mandarin, Kachave and Bhosale (2009) [14] in kagzi lime.

2. Total sugars (%)

The data on total sugars as influenced by different plant growth regulators and micronutrients of acid lime is presented in Table 1. The significant variations were noticed in the total sugars with the foliar application of growth regulators and micronutrients is presented in Table 1 The treatment T_6 - NAA (100 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%) (1.88%) followed by T_5, T_4, respectively. However, the lowest level of total sugar (0.95%) was recorded in T_8 - Control. Increased photosynthetic activity and leaf chlorophyll content may have contributed to the increased TSS of juice produced when micronutrients, particularly zinc, were added. This additional TSS in fruit juice may have been produced as a result. The TSS concentration of juice in acid lime was numerically raised by the application of the plant growth regulator, or NAA. Inspite of this, the combined effect of micronutrients and plant growth regulators enhanced the TSS in acid lime fruit. These results are supported by the findings of Ingle *et al*. (2002) [11] observed an increase in the sugar content of acid lime with foliar application of zinc and iron. Kachave and Bhosale (2009) [14] who observed increase in reducing, non-reducing and total sugar content in Kagzi lime with application of NAA and zinc. Similar results were observed by Nawaz *et al*. (2011) [16], Neware *et al*. (2015) [17].

3. Reducing sugar (%)

The data on reducing sugars as influenced by different plant growth regulators and micronutrients of acid lime is presented in Table 1. The significant differences were noticed in reducing sugars with the foliar application of growth regulators and micronutrients. The higher amount of reducing sugar (0.92%) was recorded in T_6- NAA (100 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%) (0.95%) followed by T_5, T_4, respectively. However, the lowest level of reducing sugar (0.54%) was recorded in T_8- Control. The hydrolysis of complex polysaccharides into simple sugar, the production of metabolites, the quick transfer of minerals and photosynthetic products from other parts of the plant to the developing fruits, and the mobilization of carbohydrates from source to sink may all contribute to an increase in sugar content when NAA is applied. These results are supported by the findings of Ingle *et al*. (2002) [11] observed an increase in the sugar content of acid lime with foliar application of zinc and iron. Kachave and Bhosale (2009) [14] who observed increase in reducing, non-reducing and total sugar content in Kagzi lime with application of NAA and zinc. Similar results were observed by Nawaz *et al*. (2011) [16], Neware *et al*. (2015) [17].

4. Non-reducing sugars (%)

The data on non-reducing sugars as influenced by different plant growth regulators and micronutrients of acid lime is presented in Table 1. The non- reducing sugar content of fruits varied significantly among the treatments is presented in Table 1. The highest percent of non- reducing sugar (0.94%) was recorded in T_6-NAA (100 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%) followed by T_5, T_4 respectively. However, the lowest level of non- reducing sugar (0.31%) was recorded in T_8 - Control. The total sugar content of fruit juice was also found to be effectively increased by foliar administration of micronutrients, particularly Zn. This may be because tryptophan, a precursor to IAA and a stimulant of several physiological processes in plant tissue, is actively synthesized when zinc is present. Additionally, zinc plays a catalytic role in the oxidation process and is crucial for sugar metabolism. These results are supported by the findings of Ingle *et al*. (2002) [11] observed an increase in the sugar content of acid lime with foliar application of zinc and iron. Kachave and Bhosale (2009) [14] who observed increase in reducing, non-reducing and total sugar content in Kagzi lime with application of NAA and zinc. Similar results were observed by Nawaz *et al*. (2011) [16], Neware *et al*. (2015) [17].

Table 1: Effect of foliar application of plant growth regulators and micronutrients on quality parameters of acid lime cv. Balaji.

Treatments	Total soluble solids (ºBrix)	Total sugar (%)	Reducing sugars (%)	Non-Reducing sugar (%)
T_1	6.86	1.57	0.78	0.79
T_2	7.05	1.68	0.80	0.88
T_3	6.55	1.63	0.82	0.81
T_4	7.12	1.67	0.84	0.83
T_5	7.26	1.72	0.86	0.86
T_6	7.50	1.88	0.92	0.94
T_7	6.58	1.24	0.64	0.60
T_8	6.50	0.85	0.54	0.31
Mean	6.92	1.53	0.77	0.75
SEm (±)	0.11	0.02	0.01	0.01
CD at 5%	0.35	0.08	0.04	0.04

5. Titrable acidity (%)

Data regarding the effect of different plant growth regulators and micronutrients on titrable acidity is reported in Table 2. The results revealed that there was significant increase in the titrable acidity content of fruit due to application of different treatments. Among different treatments, foliar application of T_6 –NAA (100 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%) recorded the highest titrable acidity content (7.89%) than all other treatments. It was followed by T_5 -NAA (50 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%) (7.87%) which are on par respectively. The treatment T_8 - Control had lowest titrable acidity content (6.02%). As the concentration was raised, NAA's acidity increased. It might be caused by an increase in total soluble solids. The fruits exposed to micronutrients and NAA also had the highest levels of acidity when foliar spray concentrations were increased in comparison to controls. An rise in osmotic pressure brought on by cell growth carried on by auxins, which results in an accumulation of organi acids, could be the cause of the increase in acidity. The results are also in accordance with the findings of Ebeed et al. (2001) [9] in mango, Nawaz *et al*. (2008) [16] in kinnow mandarin, Kachave and Bhosale (2009) [14] in Kagzilime, Debaje *et al.* (2011) [7] and Jain *et al*. (2014) [13] in Nagpur Mandarin, Bhati *et al*. (2016) [4] and arunadevi *et al*. (2019) [2].

6. Ascorbic acid (mg/100 g)

Data regarding the effect of different plant growth regulators and micronutrients on ascorbic acid of acid lime is furnished in Table 2. The data given in Table 2 result that maximum ascorbic acid (30.15 mg/100 ml juice) was recorded in the treatment T_6-NAA (100 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%) it was statistically on par with T_5, T_4, T_3 respectively where as minimum ascorbic acid (24.60 mg/100 ml juice). The foliar spray of micronutrients greatly boosted the ascorbic acid concentration in the fruit juice. Because ascorbic acid is produced from sugar, a higher amount of sugar in fruits treated with micronutrients may be the cause of the rise in ascorbic acid content in fruit juice (Brahmachari *et al*. 1997) [5]. The micronutrient treatments may possibly have increased the ascorbic acid level of fruit juice by decreasing the activity of enzymes that break down nutrients. The results are also in accordance with the findings of Ebeed *et al.* (2001) [9] in mango, Nawaz *et al*. (2008) [16] in kinnow mandarin, Kachave and Bhosale (2009) [14] in Kagzi lime, and Jain *et al*. (2014) [13] in Nagpur Mandarin and Bhati *et al*. (2016) [4].

7. Juice (%)

The data given in Table 2 result that maximum as juice% (49.15%) was recorded in the treatment T_4 - GA_3 (50 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%) it was statistically on par with T_2, T_3 respectively. The lowest percent juice (36.50%) was recorded with treatment T_8 - Control respectively. The role of GA_3 and micronutrients in hormone metabolism, accelerated cell division, cell elongation, and cell expansion is another reason why juice percentage may be increased. Results regarding juice percentage were found to be in consonance with that of. Kachave and Bhosale (2007) [14] in acid lime, Shinde *et al*. (2008) [19], Dixit *et al*. (2013) [8] in Litchi, Jagtap *et al*. (2013) [12] and Bhati *et al*. (2016) [4].

8. Shelf life (days)

The data with respect to Shelf life as influenced by various plant growth regulators and micronutrients of acid lime is presented in Table 2. The number of days required from fully ripening of fruits until spoilage is the shelf life. Data recorded on shelf life of acid lime was observed in daily basis. The data given in table 2 result T_4 - GA_3 (50 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) +Boron (0.1%), (23.70 days) was statistically on par with T3 respectively. The lowest shelf life was (14.33 days) was recorded with treatment T_8 - Control respectively.

Table 2: Effect of foliar application of plant growth regulators and micronutrients on quality parameters of acid lime cv. Balaji.

Treatments	Titratable acidity (%)	Ascorbic acid (mg/100 g)	Juice (%)	Shelf life (days)
T_1	6.66	27.97	44.73	16.34
T_2	6,97	28.64	47.93	17.02
T_3	7.07	28.90	46.90	21.68
T_4	7.26	28.97	49.15	23.70
T_5	7.87	29.33	45.85	19.36
T_6	7.89	30.15	42.15	19.24
T_7	5.36	25.88	38.90	15.72
T_8	6.02	24.60	36.50	14.33
Mean	6.88	28.05	44.01	18.42
SEm (±)	0.11	0.46	0.74	0.32
CD at 5%	0.34	1.41	2.25	0.96

Table 3: Effect of plant growth regulator and micronutrients on benefit: cost ratio of acid lime cv. Balaji.

Treatments	Total cost of cultivation (Rs/ha)	Fruit yield (t/ha)	Gross income (Rs/ha)	Net income (Rs/ha)	B : C Ratio
T_1	75218	5.21	182678	107460	1.42
T_2	75235	5.59	195751	120516	1.60
T_3	76037	7.44	260512	184475	2.42
T_4	76874	8.50	297598	220724	2.87
T_5	75254	6.15	215570	140316	1.86
T_6	75308	6.03	211324	136016	1.80
T_7	75201	4.97	174096	98895	1.31
T_8	75000	4.31	150850	75850	1.01

The benefit: cost ratio differed significantly among treatments of acid lime (*Citrus aurantifolia* Swingle) cv. Balaji fruits as presented in the Table 3. The maximum benefit: cost ratio (2.84) was found in trees sprayed with T_4 - GA_3 (50 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%) followed by T_3 Whereas minimum benefit: cost ratio was obtained in T_8 - control (1.01). Although the treatment cost high with GA_3 however with good quality acid lime fruits have fetched higher price and hence, maximum BC ratio was realized in the trees sprayed with GA_3 (50 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%).

Conclusion

Based on the study, it was concluded that, the growth regulators and micronutrients combination resulted in increasing quality of acid lime fruits. The treatment NAA (100 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%) was the best treatment for TSS, total sugars, reducing sugars, non-reducing sugars, ascorbic acid, tritable acidity. The treatment GA_3 (50 ppm) + $ZnSO_4$ (0.5%) + $FeSO_4$ (0.2%) + $MgSO_4$ (0.2%) + $MnSO_4$ (0.2%) + Boron (0.1%). Was best treatment for increasing juice percent and shelf life in acid lime.

Future scope

Studies on the influence of combination of plant growth regulators and micronutrient on yield, economics, quality and shelf life of acid lime under high density planting can be taken up.

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Conflict of interest: None

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