



Impact of Gibberellic Acid and Growth Stimulants on Productivity Metrics of Kagzi Acid Lime (*Citrus aurantifolia* Swingle)

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ABSTRACT

Background: Acid lime is a nutrient-intensive crop and it needs sufficient mineral nutrition for healthy growth and development and there was a need to study the effect of GA₃ and growth-promoting chemicals as a nutrient source for acid lime cv. Kagzi trees. The reason to undertake this research was based on the impact of GA₃ and growth-inducing chemicals on better nutrient supplementation, quick nutrient intake, better photosynthates translocation and carbohydrates mobilization and its effect on production parameters in acid lime cv. Kagzi trees.

Methods: A field trial was carried out at the Fruit Instructional Farm, Department of Fruit Science, College of Horticulture and Forestry, Jhalawar between June 2023 and December 2023 in a 15-year-old established orchard of acid lime cv. Kagzi. The trial was set up following a randomized block design with three replications. It involved the application of nine different treatments through foliar spraying, which included GA₃ and various growth-promoting chemicals such as KNO₃, thiourea and salicylic acid.

Result: According to the findings of the current study, the foliar application of T₄ treatment (GA₃ @ 100 mg/l + KNO₃ @ 2%) proved to be more successful in enhancing the production parameters of acid lime cv. Kagzi. The application of T₄ treatment comprising GA₃ @ 100 mg/l + KNO₃ @ 2 % resulted in the shortest time to initiate flowering (40.05 days), the briefest flowering period (53.79 days), the highest number of flowers per shoot (144.66), the greatest fruit set percentage (69.08%) and the highest fruit retention percentage (47.37%). The foliar application of treatment T₄ (GA₃ @ 100 mg/l + KNO₃ @ 2%) proved to be the most successful in increasing the fruit count per tree (448.00), fruit weight (70.00 g) and yield (31.35 kg/tree) in Kagzi acid lime trees.

Key words: Acid lime, GA₃, Potassium nitrate, Thiourea.

INTRODUCTION

Acid lime (*Citrus aurantifolia* Swingle.) is a globally significant subtropical fruit crop belonging to the Rutaceae family. With a somatic chromosome number of 2n=18, it is believed to have originated in northeastern India and the southern Himalayan region, later spreading to the Middle East and other tropical and subtropical areas. In India, acid lime ranks as the third most important citrus crop after mandarins and sweet oranges. Currently, India leads global acid lime production with an area of 3.09 lakh hectares yielding 37.71 lakh metric tonnes (Anonymous, 2023-24). Within the citrus family, fruit drop is highly prevalent, with premature blooming and subsequent fruit drop posing significant challenges for horticulturists. Blooming, the initial step toward harvest, is influenced by various physiological and pathological factors. While pathological losses stem from infections, physiological causes include temperature and humidity fluctuations, poor nutrition, hormonal imbalances and inadequate soil moisture. Phyto-hormones or plant growth regulators, naturally occurring compounds in plants, help regulate flower bud development processes and address flowering constraints.

Plant growth regulators, particularly GA₃, enhance ovary development, regulate flower initiation and stimulate fertilization for improved fruit set. GA₃ plays multiple roles in plant growth processes, including activating hydrolytic

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enzymes, forming floral primordia, initiating flowering and developing floral organs. Its application promotes cell elongation and differentiation in acid lime plants' meristematic tissues, leading to better flower inhibition and synchronization (Gupta *et al.*, 2023).

Potassium nitrate, a fertilizer containing potassium and nitrogen, is vital for flowering, fruit set and quality in

acid lime trees. Potassium facilitates pollination and fertilization by supporting healthy pollen grain development and enhances fruit quality through promoted cell division, expansion and sugar accumulation. It also aids in carbohydrate and nutrient transport within the plant (Khan and Nabi, 2023).

Thiourea, an organic molecule structurally similar to urea but containing sulphur instead of oxygen, is increasingly utilized to enhance plant growth and productivity under both normal and challenging environmental conditions. It strengthens plant defenses against diseases, extreme heat, oxidative stress from drought, salinity and heavy metal toxicity.

Salicylic acid functions as a plant growth regulator by promoting cellular division, elongation and differentiation, supporting overall growth and development. It protects against biotic stresses from bacteria, fungi and viruses while helping lime trees withstand abiotic stressors like heat, cold and drought. As documented by Mishra and Dash (2018), GA₃ and growth-enhancing agents benefit acid lime variety Kagzi during the rainy season by improving water management and enhancing photosynthate translocation due to increased moisture availability.

MATERIALS AND METHODS

The study "Impact of GA₃ and growth-enhancing substances on production metrics of acid lime (*Citrus aurantifolia* Swingle.) cv. Kagzi" was conducted from June to December 2023 at the College of Horticulture and Forestry, Jhalawar (Agriculture University, Kota). The research utilized 15-year-old acid lime trees to evaluate the effects of GA₃ and growth-promoting chemicals during the rainy season. The experimental site consisted of 54 acid lime plants arranged in a square layout with 6 m × 6 m spacing in an established Kagzi orchard. Nine treatments were studied, including a Control and various combinations of GA₃ with growth-promoting agents (KNO₃, Thiourea and Salicylic acid). Three foliar sprays were applied at monthly intervals: First on June 10th, second on July 10th and third on August 10th, 2023. The experiment followed a randomized block design with three replications on predominantly clay loam soil classified as heavy clay in texture.

Details of treatments

T₀: Control (water spray)

T₁: GA₃ @ 50 mg/l

T₂: GA₃ @ 100 mg/l

T₃: GA₃ @ 50 mg/l + KNO₃ @ 1%

T₄: GA₃ @ 100 mg/l + KNO₃ @ 2%

T₅: GA₃ @ 50 mg/l + Thiourea @ 1%

T₆: GA₃ @ 100 mg/l + Thiourea @ 2%

T₇: GA₃ @ 50 mg/l + Salicylic acid @ 100 mg/l

T₈: GA₃ @ 100 mg/l + Salicylic acid @ 200 mg/l

The study measured several key parameters to assess the treatments' impact on flowering and fruit production. These included the time to first flowering (counted from foliar application to initial flower bud initiation), the total

flowering duration (from first to last flower bud initiation) and the average number of flowers per shoot (calculated from five randomly selected shoots). Fruit set percentage and fruit retention at harvest were determined through specific formulas using observations from five randomly tagged shoots per treatment replication. The total fruit yield was assessed by manually counting fruits per tree at harvest. For fruit quality evaluation, three randomly selected fruits from each treatment replication were weighed using a Sartorius BS 224 S electronic balance to calculate average fruit weight. The overall yield per tree was determined by weighing the total harvested fruits for each treatment using an electronic balance. This comprehensive assessment enabled a thorough evaluation of how growth-promoting treatments influenced the flowering process, fruit development and overall tree productivity.

RESULTS AND DISCUSSION

Flowering parameters

The results of flowering parameters, including days to first flowering, total span of flowering and bloom quantity per shoot, demonstrated that foliar application of various treatment combinations comprising GA₃, KNO₃, thiourea and salicylic acid significantly influenced these characteristics. The data presented in Table 1 clearly shows that leaf-applied GA₃ and growth-promoting chemicals at different concentrations and distinct levels had a significant effect on acid lime cv. Kagzi trees. Specifically, these treatments reduced the number of days to first flowering, minimized the total span of flowering and increased the bloom quantity per shoot. The most rapid flowering response (40.05 days) and minimum total span of flowering (53.79 days) were recorded in acid lime cv. Kagzi trees in response to the T₄ treatment (GA₃ @ 100 mg/l + KNO₃ @ 2%). Conversely, the maximum number of days to first flowering (47.61 days) and the maximum total span of flowering (61.92 days) were observed in the T₀ (control) treatment. The relatively improved minimum number of days to the initial flowering and the shortest overall flowering duration in the T₄ treatment can be linked to the prompt influence of GA₃ on the acceleration and swift movement of photosynthates and flowering enhancers, which altered the destiny of vegetative buds into reproductive ones, thereby hastening flower development and facilitating early flower anthesis in acid lime, a conclusion that is corroborated by the research conducted by (Singh *et al.* 2018) in chrysanthemum. This suggests that the application of GA₃ could be a critical factor in optimizing flowering times, potentially leading to enhanced yield and quality in acid lime cultivation. The quick transformation of vegetative buds into floral buds in acid lime cv. Kagzi trees can be potentially enhanced when GA₃ at 100 mg/l is used together with KNO₃ at 2%. The current findings align with the studies conducted by Sarker and Rahim (2013) on mango, Deshlehra *et al.* (2019) focusing on acid lime and Mandloi *et al.* (2021) regarding acid lime. The highest

number of flowers per shoot (144.66) was observed in acid lime cv. Kagzi trees treated with T_4 , which included GA_3 at 100 mg/l and KNO_3 at 2%. Conversely, the lowest flower count per shoot (122.67) was noted in the T_0 (control) treatment. The increase in flowers per shoot in the T_4 treatment, relative to the other treatments, can likely be explained by the synergistic effect of GA_3 and KNO_3 as foliar treatments in acid lime trees.

Additionally, the positive impact of GA_3 in breaking dormancy and stimulating rapid cell division, in combination with KNO_3 , may have contributed to the availability of essential mineral elements, particularly potassium and nitrogen (Zhang *et al.*, 2024 and Elsayed *et al.*, 2024). These are vital for chlorophyll synthesis, leading to increased vigor and ultimately resulting in a higher floral count per shoot in the acid lime cultivar Kagzi trees (Thirugnanavel *et al.*, 2007; Rai *et al.*, 2018, Tagad *et al.*, 2018, Deshlehra *et al.*, 2019; Mandloi *et al.*, 2021 and Karakal *et al.*, 2023 in acid lime, Patel and Tripathi 2024).

Fruit setting parameters

The foliar application of various treatment combinations, including GA_3 , KNO_3 , thiourea and salicylic acid, significantly affected fruit setting parameters such as fruit set percentage and fruit retention at harvest. The results outlined in Table 1 show that applying GA_3 and growth-promoting chemicals at different concentrations, in different treatment combinations, has a significant impact on improving fruit set percentage and fruit retention at harvest in acid lime cv. Kagzi trees.

The Kagzi variety of acid lime trees that were treated with T_4 (consisting of GA_3 at 100 mg/l and KNO_3 at 2%) showed the highest fruit set at 69.08% and fruit retention at harvest at 47.37%. In contrast, the control (T_0) recorded a lower fruit set at 60.02% and fruit retention at harvest at 29.05%. The maximum developmental fruit persistence rate attained consequent to T_4 treatment might be attributable to better pollen functionality and pollen tube elongation in acid lime cv. Kagzi trees. The application of GA_3 might have enhanced stigma receptivity and promoted the growth of pollen tubes, leading to successful fertilization and increased fruit set in acid lime cv. Kagzi. The role of

GA_3 in the reduction of fruit drop is of paramount importance as evident in the present results and GA_3 supports in strengthening of the abscission zone of fruit-bearing shoots which may be one of the reasons for enhanced fruit retention in acid lime cv. Kagzi trees (Patel *et al.*, 2024). The combination of GA_3 and KNO_3 enhances fruit set efficiency and crop persistence in acid lime cv. Kagzi trees. The increased success in fruit setting is linked to beneficial amino acids and vitamins that support potassium's role in carbohydrate transport to developing fruitlets. Additionally, KNO_3 contributes to chlorophyll buildup, stimulating photosynthesis and improving fruit set when applied with GA_3 at 100 mg/l and KNO_3 at 2%. The potassium helps in osmoregulation by maintaining turgor balance and thereby supports fruit retention along with optimization of photosynthesis rate and maintaining hormonal balance within the Kagzi lime trees. The current findings corroborate those published by Nahar *et al.* (2010), Sarker, Rahim (2013), Patel *et al.* (2016) in mango, Joshi *et al.* (2016) in sapota, Chaudhary *et al.* (2018) in aonla, Rai *et al.* (2018), Deshlehra *et al.* (2019) in acid lime.

Yield parameters

The yield attributes of acid lime cv. Kagzi trees - including number of fruits per tree, fruit weight (g) and yield (kg/tree) - were significantly influenced by foliar application of different treatment combinations of GA_3 , KNO_3 , thiourea and salicylic acid, as shown in Table 2. These treatment combinations significantly increased the number of fruits per plant, fruit weight (g) and yield (kg/tree) across various treatments.

The highest number of fruits per tree (448.00) was recorded in acid lime cv. Kagzi trees treated with GA_3 at 100 mg/l + KNO_3 at 2% (T_4 treatment), while the lowest (422.33) was observed in the control (T_0 treatment) receiving only water spray. The increased fruit yield can be attributed to gibberellic acid's role in enhancing flower production, improving fruit formation and increasing fruit retention (Prabhu *et al.*, 2017). Furthermore, potassium nitrate significantly increased chlorophyll levels and leaf growth per shoot, directly contributing to fruit development (Salman *et al.*, 2010). These results align with previous research on

Table 1: Influence of gibberellic acid and growth stimulants on blossom development and fruit formation of Kagzi acid lime.

Treatment details	Number of fruits per tree	Fruit weight (g)	Yield (kg/tree)
T_0 (Control)	422.33	39.66	16.75
T_1 (GA_3 @ 50 mg/l)	428.00	42.00	17.97
T_2 (GA_3 @ 100 mg/l)	431.33	44.66	19.26
T_3 (GA_3 @ 50 mg/l + KNO_3 @ 1%)	442.00	61.66	27.25
T_4 (GA_3 @ 100 mg/l + KNO_3 @ 2%)	448.00	70.00	31.35
T_5 (GA_3 @ 50 mg/l + Thiourea @ 1%)	434.33	50.00	21.71
T_6 (GA_3 @ 100 mg/l + Thiourea @ 2%)	437.66	56.66	24.79
T_7 (GA_3 @ 50 mg/l + Salicylic acid @ 100 mg/l)	435.00	48.00	20.88
T_8 (GA_3 @ 100 mg/l + Salicylic acid @ 200 mg/l)	438.66	50.00	21.93
SEm ($\pm$)	1.00	2.96	1.30
CD (5%)	3.00	8.90	3.91

Table 2: Influence of gibberellic acid and growth promoters on productivity indicators of Kagzi Acid lime.

Treatment details	Days to first flowering (DFF)	Total span of flowering (TSF)	Number of flowers per shoot	Fruit set (%)	Fruit retention (%)
T ₀ (Control)	47.61	61.92	122.67	60.02	29.05
T ₁ (GA ₃ @ 50 mg/l)	44.10	59.87	123.66	61.08	30.84
T ₂ (GA ₃ @ 100 mg/l)	41.96	57.87	126.33	61.23	32.82
T ₃ (GA ₃ @ 50 mg/l + KNO ₃ @ 1%)	41.56	58.52	132.66	63.83	42.56
T ₄ (GA ₃ @ 100 mg/l + KNO ₃ @ 2%)	40.05	53.79	144.66	69.08	47.37
T ₅ (GA ₃ @ 50 mg/l + Thiourea @ 1%)	42.36	59.83	127.66	61.65	35.21
T ₆ (GA ₃ @ 100 mg/l + Thiourea @ 2%)	42.90	58.18	129.00	62.09	36.83
T ₇ (GA ₃ @ 50 mg/l + Salicylic acid @ 100 mg/l)	41.22	58.95	128.66	61.14	34.47
T ₈ (GA ₃ @ 100 mg/l + Salicylic acid @ 200 mg/l)	42.67	58.01	127.00	61.97	34.45
SEm (±)	0.53	0.87	0.82	0.60	0.73
CD (5%)	1.60	2.61	2.47	1.82	2.21

Mandarin by El-Otmani (2004) and on Mango by Yeshitela *et al.* (2004).

The acid lime variety Kagzi demonstrated the highest fruit weight of 70.00 g following the T₄ treatment (100 mg/l GA₃ combined with 2% KNO₃), while the control treatment (T₀) yielded the lowest fruit weight of 39.66 g. The increased fruit weight can be attributed to gibberellic acid's role in promoting cell expansion, elongation and proliferation. Additionally, potassium plays a vital role in enhancing fruit weight through improved photosynthetic activities, leading to increased food storage. As an enzymatic catalyst, potassium is involved in ATP production, which regulates the photosynthesis rate and enables plants to accumulate substantial food within the fruit (Kumar *et al.*, 2023). ATP is also crucial for various plant functions, including cell division. Fruit size is determined by cell number and size, with the central vacuole occupying a significant portion of cell volume. While fruit expansion is key to growth and development, potassium enhances fruit weight by facilitating the transfer of photosynthates to the fruit. The outcomes of the current research align with those documented by Yeshitela *et al.* (2004) in mango, Debaje *et al.* (2011) in acid lime, Jagtap *et al.* (2013) in acid lime, Joshi *et al.* (2016) in sapota, Chaudhary *et al.* (2018) in aonla, Rai *et al.* (2018) in acid lime, Karakal *et al.* (2023) in acid lime and Khan and Nabi (2023) in sweet lime.

The acid lime variety Kagzi trees receiving T₄ treatment (GA₃ at 100 mg/l combined with KNO₃ at 2%) exhibited the highest yield of 31.35 kg/tree, while the control treatment (T₀) showed the lowest yield at 16.75 kg/tree. Increased concentrations of KNO₃ and GA₃ resulted in a higher number of acid lime fruits per tree. This yield enhancement may stem from reduced vegetative growth, which promotes better flowering, fruit setting and improved fruit retention. Moreover, a larger quantity of metabolites was directed towards reproductive growth, particularly towards the fruit 'sink'. GA₃ contributed to raising yields and boosting fruit production by facilitating quicker mobilization of stored metabolites or photosynthates and supporting auxin

biosynthesis. Notably, foliar application of KNO₃ resulted in the greatest number of flowers, fruit production and total yield. These findings align with previous research by El-Otmani (2004) on mandarin, Thirugnanavel *et al.* (2007) on acid lime, Nahar *et al.* (2010) on mango, Jagtap *et al.* (2013) on acid lime, Joshi *et al.* (2016) on sapota, Chaudhary *et al.* (2018) on aonla and Tagad *et al.* (2018) on acid lime.

CONCLUSION

In this investigation of acid lime cv. Kagzi, the response to foliar applications of GA₃, KNO₃, thiourea and salicylic acid in various combinations was examined for flowering, fruit set and yield outcomes. The study aimed to assess the efficacy of GA₃ and growth-inducing chemicals. A comparative evaluation of different treatment combinations revealed that the T₄ treatment (GA₃ @ 100 mg/l + KNO₃ @ 2%) notably enhanced production parameters, including flowering, fruit set and yield of Kagzi acid lime, particularly in the Vertisols of the Jhalawar district.

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Authors contribution

Prerak Bhatnagar provided the main concept of the work. Lab work and analysis were performed by Sunil Kumar Bairwa. Jitendra Singh, Kavita Aravindakshan, Hemraj Chhipa and Rahul Chopra helped with formatting. All authors read and approved the manuscript.

Disclaimers

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Ethical approval

All authors declare that this manuscript does not involve studies including animals or human beings.

Conflict of interest

The researchers declare no competing interests related to the research presented in this paper.

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