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RESEARCH ARTICLE

Efficacy of foliar feeding of plant bioregulators on yield attributes and economic analysis of acid lime

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Abstract

The current study was done at the Odisha University of Agriculture and Technology, Bhubaneswar, during 2019–2020 and 2020–2021. Acid lime, scientifically known as *Citrus aurantifolia* Swingle, is a member of the Rutaceae family. It has its origins in India and possesses a chromosomal count of 2n=18. Citrus fruits are an important crop cultivated commercially in over 50 nations worldwide. Kagzi lime is one of the important citrus crop occupying more than 10 per cent of the total area under citrus cultivation in India. The objective of this research was to assess the most appropriate plant bioregulator in terms of fruit productivity and economics. This investigation found that the usage of growth regulators, such as 2,4-D (at 10 and 20 ppm), GA_3 (at 5 and 10 ppm) , NAA (at 100 and 200 ppm) , SA (at 100 and 200 ppm), Spermidine (at 0.001 mM and 0.002 mM), Putrescine (at 0.01 mM and 0.02 mM), Brassinosteroid (at 0.1 ppm and 0.5 ppm) and an untreated control, had an impact on the production characteristics of acid lime Kuliana local. The data on crop productivity and its characteristics were documented throughout the corresponding seasons in both years. Plant bioregulators with the highest efficacy for increasing fruit production were discovered by evaluating the performance of different growth characteristics. The variance in plant bioregulators has a significant impact on yield. Brassinolide exhibited the most significant impact on number of fruits per tree, with an average number of 379.02 fruits. Additionally, it resulted in a higher yield of 12.46 kg per tree. The minimum days to flower bud initiation (41.64), days to 50 % flowering (47.96), maximum number of flowers per cluster (21.47), number of flower clusters per tree (39.89) and fruit weight (33.71 g) were also observed as significant related to brassinosteroid application compared to other treatments. Minimum number of seeds per fruit (5.97) was seen in the treatment of GA_3 at 10 ppm. There was no significant difference among the treatments on peel thickness. Furthermore, the use of brassinosteroids led to a higher benefit-cost ratio of 2.96 compared to the remaining treatments and the untreated control group in both seasons of the study. Our findings demonstrated that the treatment with a brassinosteroid known as Brassinolide yielded the greatest outcomes in terms of yield attributes for acid lime.

Keywords

Acid lime; benefit cost ratio; bio regulators; growth; yield

Introduction

Acid lime, scientifically known as *Citrus aurantifolia* swingle, is a member of the Rutaceae family. Native to India, it has since spread to the Middle East and many subtropical and tropical regions. While mandarin, grapefruit and sweet orange thrived in sub-tropical climates, lime and lemon required tropical climates to grow successfully (1).

Acid lime fruits have significant economic importance due to their extensive output of both fresh harvest and various processed forms. In India, acid lime fruits are grown across a land area of 322000 ha, resulting in a production of 3517000 MT (2). When it comes to citrus species, lime holds 25720 ha in area and 288030 MT in production. Indian states in which it is mostly grown are Andhra Pradesh, Maharashtra, Tamil Nadu, Gujarat, Rajasthan and Bihar. The primary citrus-producing nations include Brazil, Spain, the United States, Israel, Morocco, China, Mexico, Russia, India, Canada and South Africa. Acid lime fruit grows best in the range of temperatures between 13 °C and 37°C. Temperature below 40 °C is harmful for the young plants (3).

India cultivates a wide variety of acid lime cultivars that exhibit variability in flavour and taste. The Acid lime cv. kuliana lime is a native, high-quality variety of landrace found in the Mayurbhanj area of Odisha.

Kuliana lime is a locally valued variety known for its large size and high juice content. It is predominantly cultivated in the Mayurbhanj area of Odisha. The crop is conventionally cultivated in the village of Kuliana, from which it derives its name. It spans an area of 500 ha in the Mayurbhanj district and is extensively farmed on both banks of the Budhabalanga River (4). India cultivates a wide variety of acid lime cultivars, each with distinct flavours and tastes. Kuliana lime is a regional kind of citrus that is cultivated abundantly in the Mayurbhanj district of Odisha. This is due to the area's ideal hot summers and cold winters, which are particularly favourable for its growth.

Kuliana plants exhibit a small and shrubby growth habit, characterized by the presence of pointed spines. It is widely known as Nimbu or sour lime. The fruit rind is thin and silky and turns into a greenish yellow colour when it reaches maturity. The leaves are compact and have diminutive, pallid green, widely lanceolate, obtuse leaves with clearly winged petioles. Flower buds and blossoms are small in size and blossom continuously, but primarily in the seasons of spring and summer. The flowers are of white shade and possess a large number of stamens. They are produced either on the side of the leaves or at the ends and they can be found alone or in groups. The fruits are very small, with a round or obovate shape and a generally rounded base. They have a greenish yellow colour and thin skin. The core of the fruit is solid when it reaches maturity and has a fresh, greenish colour. The juice of the fruit is strongly acidic. Seeds exhibit a diminutive size, possess a sleek texture and display a white shade in their cotyledon. Furthermore, they are characterized by a high degree of polyembryony (5).

Acid lime trees have three yearly flowering cycles, taking place in the months between January to February, June to July and September to October, known as Ambe, Mrig and Hasta bahar respectively (6). Citrus has a significant role in the country's economy. Citrus fruits are a crucial part of the human diet, offering a diverse range of essential nutrients like ascorbic acid, minerals like Fe and K, compounds called flavonoids, coumarins and fibres like pectin and roughage. The flavonoids in citrus possess a wide range of medicinal properties, such as carcinogenic, bactericidal, antioxidant and anti-anxiety properties (7).

Citrus production worldwide utilizes plant growth regulators. They are employed in orchards to stimulate or inhibit vegetative growth, to influence the process of blooming and alter fruit set and fruit growth (8). 2, 4-D serves as an herbicide. It regulates xylem differentiation and aids in cell division. NAA, often known as synthetic auxin, functions as a rooting agent. It inhibits fruit abscission and stimulates flowering and fruit development. Gibberellic acid is a plant hormone that occurs naturally. It stimulates cellular division and elongation, facilitates shoot growth and has a role in regulating dormancy (9). It has been utilized to manipulate the process of flowering and the growth of fruits. Salicylic acid is a secure substance that safeguards plants and regulates their growth. It is a phytohormone derived from phenol compounds. Succinylcholine is produced through the synthesis of phenylalanine. It is present in plants and has important functions in plant growth and development, photosynthesis, transpiration, ion absorption and transportation. Polyamines are small polycations with low molecular weight that are present in all living organisms (10). These growth regulators are a novel family of compounds that function as secondary hormonal messengers (11). Brassinosteroids are a group of phyto polyhydroxy steroids and are considered a unique form of phytohormones. They have a vital function in various plant activities, such as cell division, elongation, vascular differentiation, flowering, pollen formation and photo-morphogenesis.

Acid lime often produces many fruits when it grows, but this might negatively affect the size and quality of the fruits. In order to fetch profitable pricing in the markets, it is crucial to strive for a consistent size and high-quality harvest of acid lime through the use of cultural improvements. Occasional low fruit set and high fruit fall are significant issues in the majority of citrus species. The persistent shedding of fruit at different phases of fruit growth causes a significant decrease in crop output, resulting in minimal profitability for citrus farmers. This particular variety of crop experiences challenges in the processes of blooming, fruiting and fruit set, which ultimately leads to a decrease in overall output. There is a scarcity of knowledge on the utilization of modern plant bioregulators in the flowering stage, fruit set and yield of acid lime.

Utilizing plant growth regulators in horticulture has become crucial due to their capacity to augment fruit set percentage, fruit production and quality. Plant bioregulators can be classified into 2 categories based on the duration of their substantial use in horticulture. Farmers frequently and effectively use certain plant growth regulators. The substances encompassed in this group are auxins, GA_3, cytokinins, ethylene and ABA. In addition to these growth regulators, whose effectiveness and efficiency are familiar to us, the potential of these technologies has not yet been fully utilized at the grassroots level due to a lack of access and understanding. These substances include brassinosteroids, polyamines and salicylic acid, among others (12). Flowering in acid lime is a common occurrence in tropical and sub-tropical places, unless it is synchronised with a specific period of intense stress. With the increased demand for fruits in the summer, it is crucial to control the process of flowering in order to obtain fruit throughout the months of April and May (13). Several researchers have studied the effectiveness of traditional plant growth hormones such as auxins, 2-4 D and GA_3 in citrus. However, there has been limited research on the effectiveness of newer plant growth hormones like polyamines and polyhydroxylated steroids. Hence the experiment was carried out to evaluate the efficacy of foliar feeding of plant bioregulators on yield attributes and economic analysis in acid lime.

Materials and Methods

The research was carried out on a 6 year old acid lime cultivar called Kuliana lime. The lime trees were grown with a spacing of 4 x 4 meters at Odisha University of Agriculture and Technology, located in Bhubaneswar. The research station is geographically situated at an altitude of 25.9 m from mean sea level and the respective latitude and longitude are 20.15° N and 82.52° E.

The study investigated the effects of seven growth regulators, along with a control group, during same season of 2 consecutive years *i.e.*, 2019-2020 and 2020-2021. Research was conducted in randomized block design with 15 treatments including control and 3 replications. There were 3 spray schedules, *i. e.,* 1^{st} spray at pre-flowering stage, 2^{nd} spray at flowering stage and 3^{rd} spray at fruit set stage in the months of September, February and March respectively.

Plant bioregulators preparation and application

The plant bioregulators were dispersed in a small quantity of pure ethyl alcohol solution and then the volume was made up to 1 L by adding distilled water in order to obtain the desired solution.

A total of seven plant bioregulators were tested at 2 different levels of concentrations for each. Treatment consists of T_1: 2,4-Dichlorophenoxyacetic acid at 10 ppm, T_2: 2,4-Dichlorophenoxyacetic acid at 20 ppm, T_3: GA_3 at 5 ppm , T_4: GA_3 at 10 ppm, T_5: Napthalene acetic acid at 100 ppm, T_6: Napthalene acetic acid at 200 ppm, T_7: Salicyclic acid at 100 ppm, T_8: Salicylic acid at 200 ppm, T_9: Spermidine at 0.001 mM, T_{10}: Spermidine at 0.002 mM, T_{11} Putrescine at 0.01 mM, T_{12}: Putrescine at 0.02 mM. T_{13}: Brassinosteroid at 0.1 ppm, T_{14}: Brassinosteroid at 0.5 ppm, and T_{15}: Control (water spray) (Table 1).

The spraying was done with the help of a battery sprayer, using 0.1 per cent 'Teepol' as surfactant. The spraying operations were initiated in the early hours of clear and sunny mornings and finished within the same day.

Table 1. Treatments used in the study.

Treatments	Treatment details	Concentration
T_1	2,4-D	10 ppm
T_2	2,4-D	20 ppm
T_3	GA_3	5 ppm
T_4	GA_3	10 ppm
T_5	NAA	100 ppm
T_6	NAA	200 ppm
T_7	SA (Salicylic acid)	100 ppm
T_8	SA (Salicylic acid)	200 ppm
T_9	Polyamine (Spermidine)	0.001 mM
T_{10}	Polyamine (Spermidine)	0.002 mM
T_{11}	Polyamine (Putrescine)	0.01 mM
T_{12}	Polyamine (Putrescine)	0.02 mM
T_{13}	Brassinosteroid (BR)	0.1 ppm
T_{14}	Brassinosteroid (BR)	0.5 ppm
T_{15}	Control (water spray)	-**Table 1.** Treatments used in the study.

Days taken to flower bud initiation

Days taken for the appearance of first bud were counted from the date of first spraying November 20^{th}, 2019 and November 20^{th}, 2020 to the days taken for appearance of first bud.

Days taken to 50 % flowering

The days from date of spraying to 50 % of total flower initiation for each treatment was recorded.

Number of flowers per cluster

Flowers borne in the axile of various leaves of the tagged shoot and also those emerged newly on labelled branches were recorded. For this purpose five shoots were tagged randomly. The average number of flower buds per cluster was calculated from the data observed.

Number of flower clusters per tree

One flower cluster from each of the tagged plants were selected and distinctly labelled. Number of flowers were counted from each cluster and recorded.

Peel thickness

The peel thickness was measured using vernier calliper and expressed as millimeters (mm)

Seed number per fruit

The seed number per fruit was calculated by extracting seeds from randomly selected 10 fruits in each treatment and expressed as the seed number per fruit.

Fruit weight

The fruit weight of five randomly taken fruits under each treatment was recorded with the help of a top pan balance and the average fruit weight was expressed in grams (g).

Number of fruits per tree

Total fruits retained on trees at the time of harvest were counted and average quantity of fruits produced per tree was documented for both seasons.

Yield (kg per tree)

The fruits harvested from each tree were weighed separately in kilograms and subsequently converted into tonnes per hectare for winter season crop.

Benefit-cost ratio

The cost of cultivation was calculated by considering the expenses for spraying, fertilizers, harvesting and treatments. The gross income per hectare was calculated by multiplying the mean yield for each treatment by the market price of acid lime fruits, expressed in rupees. The cost of cultivation for each treatment was calculated by considering the expenses associated with all the operations, including the cost of spray solution, personnel costs and other related expenses. The net return was calculated by deducting the entire cultivation cost from the gross output for each treatment and it was recorded in rupees per hectare. The B:C ratio is calculated by dividing the net income by the cost of cultivation.

$$Benfit\ cost\ ratio(BCR)\,\frac{Gross\ income(Rs.)}{Expenditure(Rs.)}$$

.........Eqt. 2

Statistical analysis

The investigation carried out entirely according to the pooled randomized block trial design. SAS and MSTAT-C were the computer programs used in all statistical analyses. An ANOVA (one-way analysis of variance) was used to analyze the data. The mean separation was performed using theleast significant difference (LSD). Critical Difference (CD) at a 5 % level of significance was calculated to compare the mean values of the treatments for all the characters.

Results and Discussion

Days taken to flower bud initiation

Days taken to flower bud initiation was significantly influenced by different levels of plant growth regulators. From the pooled data (Table 2), it was observed that the minimum days taken to the emergence of flower bud (41.64 days) was recorded in the treatment T_{14} (0.5 ppm BR), which was on par with treatments T_{13} (0.1 ppm BR) T_{12} (0.02 mM PUT), T_{11} (0.01 mM PUT), T_{10} (0.002 mM SPMD),T_9 (0.001 mM SPMD) and T_6 (200 ppm NAA) and the maximum number of days taken to the emergence of flower bud (55.37 days) was recorded in T_{15}(control) during the period 2019-2020 and 2020-2021.

Days taken to 50 % flowering

Days taken to 50 % flowering was significantly influenced by different levels of plant growth regulators. From the pooled data (Table 2), it was observed that the minimum days taken to 50 % of flowering (47.96 days) was recorded in the treatment T_{14} (0.5 ppm BR), which was best to the rest of all and the maximum number of days taken to 50 % of flowering (64.31 days) was recorded in T_{15}(control) during the period 2019-2020 and 2020-2021.

Number of flowers per cluster

Number of flowers per cluster was significantly influenced by different levels of plant growth regulators. From the pooled data (Table 2), it was observed that the maximum number of flowers per cluster (22.67) was recorded in the treatment T_6 (200 ppm NAA) and the minimum number of flowers per cluster (16.67) was recorded in T_{15}(control) during the period 2019-2020 and 2020-2021.

Table 2. Efficacy of foliar feeding of plant bioregulators on days to flower bud initiation, days to 50 % flowering, number of flowers per cluster of Acid lime cv. Kuliana local.

	Days to flower bud initiation			Days to 50 % flowering			Number of flowers per cluster		
Treatments	**Season 1**	**Season 2**	**Pooled**	**Season 1**	**Season 2**	**Pooled**	**Season 1**	**Season2**	**Pooled**
2,4-D at 10 ppm	48.05	45.76	46.90	57.14	52.45	54.92	17.36	19.64	18.50
2.4-D at 20 ppm	46.91	44.69	45.80	54.73	51.64	53.18	18.36	20.46	19.41
GA_3 at 5 ppm	50.89	47.90	49.39	57.65	54.33	55.99	17.98	20.43	19.21
GA_3 at 10 ppm	50.70	46.27	48.48	56.35	51.44	53.89	19.16	21.24	20.20
NAAat 100 ppm	49.60	44.28	46.94	56.63	50.61	53.62	18.89	21.46	21.18
NAAat200 ppm	47.40	42.94	45.17	54.82	48.34	51.58	21.03	24.31	22.67
SA at 100 ppm	50.55	44.83	47.69	58.90	52.43	55.69	16.18	19.81	17.99
SA at 200 ppm	50.23	41.52	45.88	57.72	51.13	54.43	18.65	20.46	19.55
SPMD at 0.001 mM	45.94	43.35	44.64	53.94	49.66	51.80	18.34	21.34	19.84
SPMD at 0.002 mM	44.10	42.44	43.27	52.91	48.33	50.62	19.42	22.47	20.95
PUT at 0.01 mM	45.88	43.58	44.73	54.80	52.32	53.56	17.35	19.79	18.57
PUT at 0.02 mM	43.97	44.12	44.05	52.35	49.48	50.91	18.65	20.63	19.64
BR at 0.1 ppm	44.25	41.71	42.98	52.85	49.55	51.20	19.13	21.73	20.43
BR at 0.5 ppm	42.74	40.53	41.64	49.57	46.35	47.96	20.31	22.63	21.47
Control	57.15	53.58	55.37	67.09	61.52	64.31	16.89	18.45	16.67
Mean	47.89	44.50	46.19	55.83	51.31	53.58	18.51	20.99	19.75
SE (m)±	1.11	1.64	1.37	0.35	0.312	0.330	0.114	0.129	0.121
CD at 5%	3.36	5.00	3.97	1.085	0.948	0.970	0.345	0.392	0.353

SPMD -Spermidine, **PUT**-Putrescine, **BR**- Brassinosteroid

Number of flower clusters per tree

Statistical variation was observed among different treatments in both the years with respect to number of flower clusters per tree as appeared in pooled data given in Table 3. Among the different treatments, the highest number of flower clusters per tree (39.89) was recorded in the treatment T_{14} (0.5 ppm BR), which was statistically superior to the rest of the treatments. Whereas, the lowest number of flower clusters per tree was (34.97) recorded in T_{15} (control).

Peel thickness

From the pooled data given in Table 3, it was found that the influence of different growth regulators on the peel thickness of acid lime cv. Kuliana fruit was non-significant. Number of seeds per fruit

The growth regulators had significant effect on seed count per fruit in acid lime cv. Kuliana. From the data in Table 3, it was noticed that the treatment T_4 (10 ppm GA_3) had the lowest number of seeds per fruit (5.97), whereas the treatment T_9 (0.001 mM SPMD) reported the highest average seed count per fruit (7.85) for both years.

Fruit weight

Table 4 revealed that growth regulators had a considerable impact on enhancing the weight of Kuliana fruit. Among the 14 treatments used in this research, it was found that T_{14}, with a concentration of 0.5 ppm brassinosteroids, was the most efficient in boosting the weight of the fruit.

During the two consecutive years of 2019–20 and 2020–21, the treatment T_{14} with 0.5 ppm of brassinosteroids, yielded the highest recorded average fruit weight of 33.71 g. This was on par with the treatment T_{13}, which utilized 0.1 ppm of brassinosteroids and resulted in an average fruit weight of 33.48 g. The minimal weight of fruit (30.46 g) was observed in T_{15} (control). This was credited to BR for boosting the efficiency of the photosynthesis and CO_2 assimilation. The results further indicated that BR also enhanced CO_2 assimilation and expedited cell division. Thus, the utilisation of brassinosteroids resulted in an increase in fruit weight (14-16).

Number of fruits per tree

The analysis of the combined data in Table 4 revealed significant differences among the various treatments in the case of number of fruits per tree. The maximum number of fruits per tree was seen in T_{14} (0.5 ppm Brassinosteroid with an average yield of 379.02, which was on par with the treatment T_6 (200 ppm NAA) with an average yield of 373.83. The lowest yield was seen in T_{15} (control) (291.17). The rise in the number of fruits per tree could be attributed to an augmentation in the photosynthetic rate within the leaves and the subsequent transportation of a greater amount of photoassimilates. Similar findings were also observed in strawberry, Morita Navel orange, yellow passion fruit, sweet cherry, passion fruit, etc (9, 17-21).

Yield (kg per tree)

Analysis of the data in Table 4 revealed significant variation among the treatments related to the yield. The treatment T_{14} (0.5 ppm BR) had the highest recorded value of 12.46 kg per tree, followed by treatment T_{13} (0.1 ppm BR) with a value of 12.12 kg per tree. The lowest yield was seen in T_1 (control) with a value of 8.98 kg per tree. The possible

Table 3. Efficacy of foliar feeding of plant bioregulators on number of flower clusters per tree, peel thickness and number of seeds per fruit of Acid lime cv. Kuliana local.

Treatments	Number of flower clusters per tree			Peel thickness (mm)			Number of seeds per fruit		
	Season 1	Season 2	Pooled	Season 1	Season 2	Pooled	Season 1	Season 2	Pooled
2,4-D at 10 ppm	35.67	36.84	36.26	1.58	1.57	1.58	6.51	7.93	7.22
2.4-D at 20 ppm	36.80	37.43	37.12	1.63	1.61	1.63	6.67	8.09	7.38
GA_3 at 5 ppm	36.17	37.32	36.75	1.68	1.67	1.68	6.01	6.43	6.22
GA_3 at 10 ppm	37.26	38.17	37.71	1.52	1.54	1.54	5.99	5.95	5.97
NAA at100 ppm	36.54	37.15	36.85	1.67	1.70	1.69	6.52	7.99	7.26
NAA at 200 ppm	37.21	39.89	38.55	1.67	1.67	1.67	6.71	8.14	7.43
SA at 100 ppm	36.07	37.34	36.71	1.67	1.68	1.68	6.43	8.11	7.27
SA at 200 ppm	36.96	38.07	37.52	1.55	1.59	1.58	6.61	8.24	7.43
SPMD at 0.001 mM	37.11	37.11	37.11	1.65	1.64	1.63	7.62	8.09	7.85
SPMD at 0.002 mM	37.94	38.58	38.26	1.63	1.60	1.61	6.63	8.17	7.41
PUT at 0.01 mM	36.94	37.34	37.14	1.65	1.62	1.64	6.74	8.13	7.44
PUT at 0. 02 mM	37.22	38.63	37.93	1.57	1.60	1.59	6.93	8.39	7.66
BR at 0.1 ppm	37.62	39.96	38.29	1.67	1.66	1.67	6.14	7.96	7.05
BR at 0.5 ppm	38.66	41.13	39.89	1.69	1.67	1.68	6.32	8.04	7.18
Control	34.52	35.41	34.97	1.59	1.58	1.58	6.42	7.84	7.13
Mean	36.85	37.89	37.37	1.62	1.63	1.62	6.55	7.83	7.19
SE (m)±	0.088	0.116	0.103	---	---	----	0.0235	0.061	0.05
CD at 5%	0.268	0.352	0.299	NS	NS	NS	0.109	0.187	0.146

SPMD -Spermidine, **PUT**-Putrescine, **BR**- Brassinosteroid

Table 4. Efficacy of foliar feeding of plant bioregulators on fruit weight, number of fruits per tree, fruit yield (kg per tree) and benefit-cost ratio of Acid lime cv. Kuliana local.

Treatments	Fruit weight (g)			Number of fruits per tree			Fruit yield (kg pertree)			Benefit-cost ratio
	Season 1	Season 2	Pooled	Season 1	Season 2	Pooled	Season 1	Season 2	Pooled	
2,4-D at 10 ppm	30.52	31.07	30.65	292.12	335.07	313.59	8.92	10.31	9.62	2.58
2.4-D at 20 ppm	30.99	31.48	31.24	320.85	355.51	338.17	9.94	10.84	10.39	2.76
GA_3 at 5 ppm	31.74	32.06	31.90	310.88	320.48	315.67	9.87	10.27	10.07	2.59
GA_3 at 10 ppm	32.17	33.47	32.82	325.40	343.84	334.62	10.47	11.51	10.98	2.69
NAA at100 ppm	30.54	30.88	30.71	337.51	359.96	348.73	10.31	11.12	10.71	2.64
NAA at 200 ppm	31.24	31.85	31.55	346.86	400.80	373.83	11.14	12.31	11.73	2.65
SA at 100 ppm	31.34	32.47	31.91	302.49	354.36	328.42	9.48	11.51	10.49	2.56
SA at 200 ppm	31.65	32.90	32.28	336.65	381.78	359.22	10.65	12.56	11.61	2.57
SPMD at 0.001 mM	31.46	33.12	32.29	324.46	344.21	334.34	10.21	10.17	10.19	2.65
SPMD at 0.002 mM	32.14	33.55	32.84	335.44	355.46	345.45	10.78	11.93	11.35	2.85
PUT at 0.01 mM	32.36	32.88	32.62	315.18	350.68	332.92	10.20	11.53	10.87	2.73
PUT at 0. 02 mM	32.85	33.15	33.00	328.60	370.97	349.78	10.79	12.30	11.55	2.71
BR at 0.1 ppm	33.08	33.89	33.48	347.12	376.84	361.98	11.48	12.77	12.12	2.89
BR at 0.5 ppm	33.37	34.05	33.71	351.10	406.90	379.02	11.57	13.35	12.46	2.96
Control	30.43	30.49	30.46	275.18	307.16	291.17	8.37	9.60	8.98	2.43
Mean	31.725	32.401	32.064	323.32	357.60	340.46	10.28	11.47	10.87	
SE (m) ±	0.083	0.112	0.098	2.533	2.622	2.578	0.079	0.097	0.089	
CD at 5 %	0.253	0.339	0.286	7.68	7.95	7.468	0.241	0.296	0.258	

SPMD -Spermidine, **PUT**-Putrescine, **BR**- Brassinosteroid

cause could be ascribed to improved fruit size and enhanced vegetative development. The rise in the crop output could also be attributed to the augmented quantity of fruits per plant, which directly correlated with the improved fruit set. The results are consistent with the observations documented by the previous studies in custard apple (14, 21).

Foliar application of brassinosteroids can positively impact fruit yield by promoting flowering, enhancing fruit set, improving fruit quality and potentially increasing the number and size of fruits produced per tree.

Benefit-cost ratio

The benefit cost ratio varied significantly across the different treatments of acid lime cv. Kuliana, as shown in Table 4. The plants that were treated with T_{14} exhibited the highest benefit-cost ratio with 2.96, followed by T_{13} with 2.89. The low benefit-cost ratio was seen in the case of T_{15} – control treated trees with a value of 2.43. Despite the high cost of treatment with BR, the acid lime fruits of good quality commanded a higher price, resulting in the highest BC ratio in the trees that were sprayed with BR.

Conclusion

The results of the treatments on fruit yield characteristics and economic analysis indicated that the concentration of 0.5 ppm of BR applied on the acid lime produced the best outcomes in terms of the minimum number of days to flower bud initiation, days to 50 % flowering, maximum number of flowers per cluster, number of flower clusters per tree, maximum number of fruits per tree, fruit yield per tree, fruit weight and benefit-cost ratio. These results remained consistent for the two growing seasons.

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Compliance with ethical standards

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

Ethical issues: None.

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