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Preharvest foliar spray of plant growth regulators expand the harvest season and improve fruit quality of acid lime (*Citrus aurantifolia* (Christm) Swingle)

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ABSTRACT

Purpose: Lime (*Citrus aurantifolia*) is a lucrative crop with a year-round demand. However, seasonality in fruiting causes market glut. Therefore, potential of gibberellic acid (GAs), brassinolide (BL) and salicylic acid (SA) as preharvest foliar sprays on widening narrow harvest window alongside improved fruit quality were studied. **Research Method:** Experiments were performed on five-year-old 30 lime trees of cv. Monaragala Local. Trees were treated with aqueous solutions of GA (12.5, 25.0, 37.5 mg L^{-1}), BL (0.5, 1.0, 1.5 mg L^{-1}) and SA (1, 2 and 3 mmol L^{-1}) at 4-5 mm and 12-15 mm diameter stages of fruit growth. **Findings:** Two higher doses of GA (25.0 and 37.5 mg L^{-1}) delayed lime fruit maturity by ≈25 - 40 days while the highest dose of BL (1.5 mg L^{-1}) and the lowest dose of SA (1.0 mmol L^{-1}) advanced fruit maturity by ≈75-80 days significantly ($p<0.05$). Treatment with PGRs resulted in improved fruit weight, size, shape, firmness, and peel colour compared to the control. **Research limitations:** High cost of plant growth regulators specially BL hampered its commercial applicability. **Originality/Value:** preharvest foliar application of 37.5 mg L^{-1} GA which delayed the fruit maturity by ≈40 days and 1.0 mmol L^{-1} SA which hastened the maturity by ≈80 days could be recommended to expand the existing acute harvest window along with improved fruit quality.

INTRODUCTION

Exogenous application of plant growth regulators (PGRs) such as gibberellic acids (GAs), brassinosteroids (BRs) and salicylic acids (SA) have shown promising results on growth, maturation and quality of many fruits. Effects of GAs on increasing leaf area and leaf chlorophyll content (Mosa et al., 2022) and acceleration of cell division, enlargement, dry matter partitioning and mineral acquisition in developing fruitlets are well documented (Csukasi et al., 2011; Kojima 1996; Taiz & Zeiger, 2010). Pre-harvest treatment of GAs induces enlarged fruits having elongated pedicels in citrus and grapes (Taiz & Zeiger, 2010). Moreover, preharvest treatment of GAs improved fruit quality at harvest by increasing fruit weight, size and firmness (Mosa et al., 2022) of and extended postharvest life through delayed loss of colour, firmness and weight of Kinnow mandarin (Talat et al., 2020), plums (Erogul & Sen, 2016), cashew apples (Souza at al., 2016), banana (Huang et al., 2014) and mandarins (Pozeo et al., 2000). Brassinolide (BL) is the most biologically active and highly distributed type of BRs identified among plant species (Ashraf et al., 2010). Foliar applied BL translocate via phloem and are effective at very low doses, easily metabolized and ecologically safe (Ali, 2017; Taiz & Zeiger, 2010). Preharvest treatment of BL improved fruit set, weight, size, total soluble solids, vitamin C and anthocyanin in sweet cherries (Roghabadi & Pakkish, 2014) and improved the growth & quality of prickly pear (Atteya et al., 2022) boosting fruit and seed yields. Advanced ripening of tomato and table grapes after preharvest foliar application of BRs have been reported by Ali (2017) and Champa et al. (2014). SA is a natural phenolic compound which functions as a PGR, involves in glycolysis, ion uptake & transport, photosynthesis, stomatal conductance, transpiration, and chloroplasts biogenesis. SA interferes with the biosynthesis and/or action of other PGRs such as ethylene and ABA those involve in fruit ripening (Zhang et al., 2003). Preharvest SA treatment improved the quality of ber (Kanwal et al., 2021) and fig fruits (Karantzi et al., 2021), hastened berry maturity in grapes (Champa et al., 2015) and reduced the rate of degradation of carotenoids in navel oranges (Huang et al., 2008).

Lime (*Citrus aurantifolia*) is a lucrative crop having a year-round demand as it is used in domestic culinary, food processing industry, indigenous medicine and health care products. While major lime production in Sri Lanka is confined to dry and intermediate zones, the acute seasonality in fruiting causes dramatic price fluctuations throughout the year. During peak harvest season, price drops dramatically thus growers tend to leave the crop without harvesting as they cannot recover the cost of production. On the other hand, during off season price per kilogram rises to an unaffordable level (≈ 3.75-6.22 USD) to consumers (Champa & Gamage, 2020). Moreover, quality of harvested fruit quickly deteriorates limiting the marketable life to ~ 7 days under prevailing ambient conditions (30-34 ^{o}C, 70-75% RH) in Sri Lanka (Samaradiwakara et al., 2018). Unavailability of cold storage facilities makes the situation worst creating huge losses during fruiting season. In this context, manipulation of fruit growth and development to widen the existing narrow harvest window would be highly beneficial for development of lime production and processing as a sustainable agribusiness. Hence, the present study was conducted to evaluate the effect of preharvest foliar treatments of GAs, BL and SA on hastening or delaying maturity and improving important fruit quality attributes of lime (*C. aurantifolia*).

MATERIALS AND METHODS

Plant materials and experimental procedure

Field experiments were performed on five-year-old 30 lime (*Citrus aurantifolia*) trees of cv. Monaragala Local budded onto rough lemon (*C. jambhiri*) rootstocks in a medium scale commercial orchard at Anuradhapura, Sri Lanka (30-35 °C, <1750 mm/year, 120 above mean sea level (amsl), undulating and imperfectly drained soil with texture at the surface: sandy loam and subsurface: sandy clay loam). During peak blooming in *Maha* season (mid-December to mid-January) of 2016/17, fruitlets at 4-5 mm diameter were tagged with different coloured polythene strips and consecutive days were counted as days after fruit set (DAFS). Analytical grade plant growth regulators namely gibberellic acid (as GA3), brassinosteroids (as brassinolide – BL) and salicylic acid (SA) were purchased from local agent of Sigma Aldrich Co., USA. Aqueous solutions of GA (12.5, 25.0, 37.5 mg L^{-1}), BL (0.5, 1.0, 1.5 mg L^{-1}), SA (1, 2 and 3 mmol L^{-1}) and control (0.0 mg L^{-1} of PGRs) were freshly prepared and sprayed onto the foliage (5 L $tree^{-1}$) at early (4-5 mm diameter fruit size) and mid (12-15 mm diameter) stages of fruit growth until runoff. At optimum harvest maturity (Samaradiwakara et al., 2020), fruits were harvested and transported to the laboratory of National Institute of Postharvest Management (NIPHM), Anuradhapura and analysed for physicochemical attributes as described below.

Time and heat units taken to attain maturity

Harvest maturity was decided based on peel colour (60% of fruit changed deep green into olive green: *L* a* b** values were 52.5±2.1, -20.2±0.5 and 36.5±1.6 respectively) and diameter of 4.5 cm±0.2 cm using a reference chart (supplementary material). Number of days taken to achieve optimum harvest maturity was counted and delay or advancement of maturity compared to the control trees was recorded as DAFS. Growing degree days (GDDs) taken to attain optimum harvest maturity was calculated as described by Stenzel et al. (2006).

Analysis of physicochemical properties of the fruit

Thirty (30) fruit (10 per replicate) was used to measure physicochemical properties. Fruit weight was measured using a top loading balance (OHAUS; model ARA 520). Fruit length (L: stem end to style end) and diameter (D) at the equatorial region were measured by a Venire calliper. The shape index (SI) was calculated taking ratio between L: D. Peel thickness was measured by a Venire calliper after cutting the fruit into half along the equatorial region. Firmness was measured using digital fruit firmness tester (53205, Turoni, Italy). Two measurements were made (without peel) on two equatorial fruit zones at 90^{o} angle with 8 mm probe under steady slow vertically downward pressure applied until penetrates to 8 mm depth. The readings were expressed in newtons. Specific gravity (SG) was determined by water displacement method. Peel colour was measured as CIE L*, a*, b* values by chromameter (CR 400, Konica Minolta, Japan). Percent juice contents were determined with reference to individual fruit weight. Total soluble solids (TSS) were measured by a refractometer (3810, Atago PAL-1, Japan) and titratable acidity (TA) was determined as per AOAC (2005). pH of the juice was measured by a pH meter ($420A^{+}$, Thermo Orion, USA).

Experimental design and analysis

The experiment was arranged as Randomized Complete Block Design (RCBD) in triplicates (with three trees in one block). Parametric data were analysed using ANOVA, followed by Least Significant Difference test (LSD) and Chi-square test using SAS 9.1 (SAS Institute Inc., USA) and MINITAB 17 (Minitab Inc., USA) respectively.

RESULTS

Effect of GAs, BL and SA on harvest maturity of lime fruit

Both type and dose of GAs, BL and SA showed significant effect ($p<0.05$) on time and GDDs to reach harvest maturity (Fig. 1a, 1b). Fruit in control trees attained maturity 147±1 DAFS (5 months), investing 2332.6±10.6 GDDs. Application of GAs delayed lime fruit maturity in dose dependent manner. The lowest dose of GA (12.5 mg L-1) attained optimum harvest maturity 160±1 (2612.6±14.9 GDDs) DAFS while the fruit treated with middle dose (25 mg L-1) reached maturity 172±0 (2805.5±5.5 GDDs) DAFS. Fruit treated with 37.5 mg L-1 of GA achieved maturity at 187±1 (3041.9±8.8 GDDs) DAFS. When the concentration of BL increased the days to maturity was decreased. Fruit treated with the lowest concentration of BL (0.5 mg L-1) attained harvest maturity at 127±1 (2030.6±10.0 GDDs) DAFS while the middle dose (1.0 mg L-1) spent 120±0 (1916.2±5.6 GDDs) days and highest dose (1.5 mg L-1) attained maturity at 72±0 (1187.9±5.6 GDDs) DAFS. Similarly, the lowest and middle doses (1 and 2 mmol l-1) of SA attained to harvest maturity at 69±0 (1088.0±5.5 GDDs) and 67±1 (1061.3±9.0 GDDs) DAFS respectively while fruits received the highest dose (3 mmol L-1) attained maturity at 120±0 (1916.17±5.57 GDDs) DAFS.

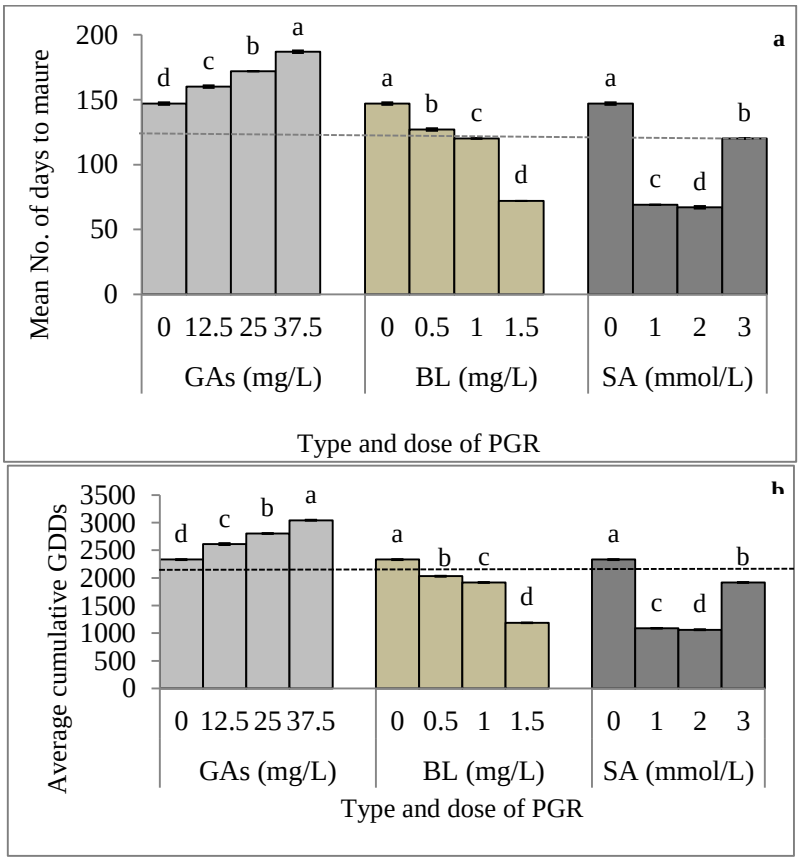


Fig. 1. Number of days (a) and cumulative growing degree days (b) to attain maturity of acid lime with preharvest treatment of gibberellic acid (GAs), brassinolide (BL) and salicylic acid (SA). Vertical bars represent standard errors of the means of three replicates (n=3) and columns with the different letters are significantly different according to LSD at $p < 0.05$. The horizontal line crosses the number of days (a) and cumulates GDDs (b) taken by the control fruit to attain optimum harvest maturity.

Physical properties of the lime fruit

Physical properties of lime fruit after treatment with different concentrations of GAs, BL and SA are shown in the Table 1 and Figure 2 respectively. All doses of PGRs, significantly ($p<0.05$) increased the fruit weight in contrast to the control except the fruit sprayed with 12.5 mg L-1 of GAs. However, reduced fruit weight shown by the fruit treated with the lowest dose of GAs was not significantly different ($p>0.05$) with the control. No significant difference was observed in fruit weights of 25.0 and 37.5 mg L-1 doses of GAs. All three doses (0.5, 1.0 and 1.5 mgL-1) of BL and SA exhibited significantly higher fruit weights compared to the control (Table 1). The lowest concentration of SA (1 mmol L-1) showed the highest fruit weight. There was no significant difference between 2 and 3 mmol L-1 of SA (Table 1).

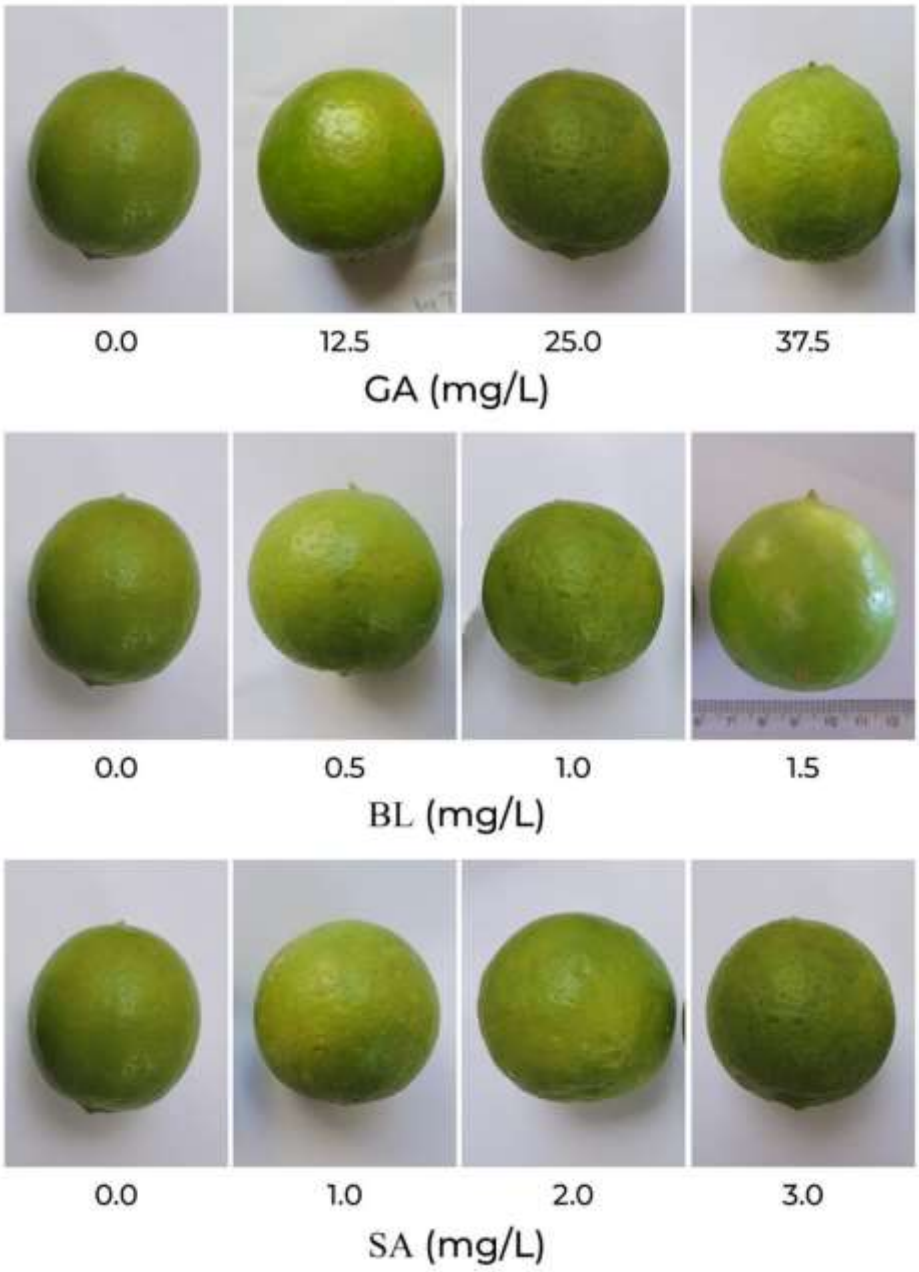


Fig. 2. Effect of preharvest treatment of gibberellic acid (GAs), brassinolide (BL) and salicylic acid (SA) on physical appearance of lime fruit at optimum harvest maturity compared to the control fruit.

Table 1. Physical properties of lime fruit subjected to foliar application of different concentrations of gibberellic acid, brassinolide and salicylic acid.

Type and dose of PGRs	Weight (g)	Diameter (cm)	Length (cm)	SI	Peel thickness (mm)	Firmness (N)	SG
GA (mgL^{-1})							
0.0 Control	41.3±2.3^{b}	4.10±0.07^{b}	4.55±0.10^{c}	1.11±0.02^{b}	1.29±0.02^{b}	120.8±5.4^{bc}	0.966±0.020^{a}
12.5	39.4±1.4^{b}	4.07±0.04^{b}	4.32±0.10^{c}	1.08±0.02^{b}	1.30±0.02^{b}	126.6±2.1^{b}	0.971±0.014^{a}
25.0	49.0±1.7^{a}	4.40±0.04^{a}	4.84±0.14^{b}	1.10±0.03^{b}	1.34±0.06^{b}	120.9±2.8^{c}	0.973±0.014^{a}
37.5	50.1±3.1^{a}	4.30±0.09^{a}	5.16±0.18^{a}	1.20±0.04^{a}	1.96±0.13^{a}	145.0±3.3^{a}	0.931±0.012^{b}
BL (mgL^{-1})							
0.0 Control	41.3±2.3^{b}	4.10±0.07^{c}	4.55±0.10^{c}	1.11±0.02^{ab}	1.29±0.02^{ab}	120.8±5.4^{a}	0.966±0.020^{ab}
0.5	52.1±2.2^{a}	4.56±0.05^{a}	5.13±0.07^{a}	1.13±0.02^{a}	1.27±0.02^{b}	122.5±3.1^{a}	0.944±0.021^{ab}
1.0	52.7±1.4^{a}	4.48±0.04^{b}	4.94±0.10^{b}	1.10±0.02^{ab}	1.31±0.02^{a}	126.1±5.8^{a}	0.971±0.013^{a}
1.5	51.0±1.7^{a}	4.49±0.08^{ab}	4.83±0.07^{b}	1.08±0.02^{b}	1.33±0.03^{a}	125.2±2.6^{a}	0.929±0.024^{b}
SA (mmol L^{-1})							
0.0 Control	41.3±2.3^{c}	4.10±0.07^{c}	4.55±0.10^{c}	1.11±0.02^{b}	1.29±0.02^{b}	120.8±5.4^{b}	0.966±0.020^{a}
1.0	56.4±2.5^{a}	4.68±0.06^{a}	5.17±0.12^{a}	1.11±0.03^{a}	1.46±0.08^{a}	126.3±5.7^{b}	0.953±0.013^{a}
2.0	51.5±2.2^{b}	4.53±0.17^{b}	4.82±0.10^{b}	1.07±0.02^{b}	1.53±0.11^{a}	108.6±6.6^{c}	0.913±0.015^{b}
3.0	50.1±2.2^{b}	4.43±0.06^{b}	5.03±0.13^{a}	1.14±0.03^{a}	1.45±0.08^{a}	143.3±2.0^{a}	0.908±0.017^{b}

Means in a column with the same letter are not significantly different (at $P \leq 0.05$) according to LSD. (n=30). SI: shape index (ratio of L: D), SG: specific gravity.

Fruit diameter and length increased ($p<0.05$) by all treatments compared to the control except the lowest dose of GAs (12.5 mg L-1) that showed a slight reduction. But this reduction was not significantly different with the control (Table 1). Though the fruit diameters of 25.0 mg L-1 and 37.5 mg L-1 of GAs did not differ significantly, length and SI were significantly higher in fruit treated with 37.5 mg L-1 giving elongated shape (Fig. 2). Application of BL increased ($p<0.05$) fruit diameter and length of which the highest values exhibited by the fruit received the lowest dose (0.5 mg L-1). The fruit SI was the highest in this treatment and it showed a significant difference with the control (Table 1). SA also showed a similar pattern of variation as BL where, the lowest dose (1.0 mmol L-1) displayed the highest ($p<0.05$) diameter and length.

GAs at the rate of 37.5 mg L-1 resulted in highest peel thickness and fruit firmness in contrast to the other two doses (12.5 and 25.0 mg L-1) and the control. However, treatment with BL showed no significant difference in relation to these two properties with the control (Table 1). SA enhanced the peel thickness significantly on the contrary to control, but there was no significant difference among the three doses (1, 2 and 3 mmol L-1) examined (Table 1). The highest fruit firmness at harvest was exhibited by 3 mmol L-1 of SA while the lowest firmness was demonstrated by the fruit received the middle dose. No significant difference was observed in relation to fruit firmness by the fruit received the lowest dose of SA compared with fruit harvested from control trees.

Lime fruit peel colour measured as lightness (L*), hue (ho) and chroma (C*) are shown in the Figure 3a, 3b and 3c respectively. Treatment with two higher doses of GAs showed significantly higher lightness compared to the control whereas no significant difference in lightness was observed when treated with BL (Fig. 3a). However, 1.0 and 2.0 mmol L-1 of SA showed lower lightness in contrast to the control (Fig. 3a). Fruit treated with 3.0 mmol L-1 of SA showed no significant difference with control fruit in peel lightness. Significantly higher greenness (higher ho) of the fruit peel ($p<0.05$) was observed in the fruit treated with 0.5 mg L-1 BL and 3.0 mmol L-1 SA while the lowest peel greenness was exhibited by fruit treated with 25.0 mg L-1 GAs compared to control fruit (Fig. 2 and 3b). Significantly higher

saturation (Fig. 3c) was observed in sample treated with 37.5 mg L-1 of GA whereas significantly lower saturation values were displayed by fruit treated with 1.5 mg L-1 of BL and the two lower doses (1.0 and 2 mmol L-1) of SA.

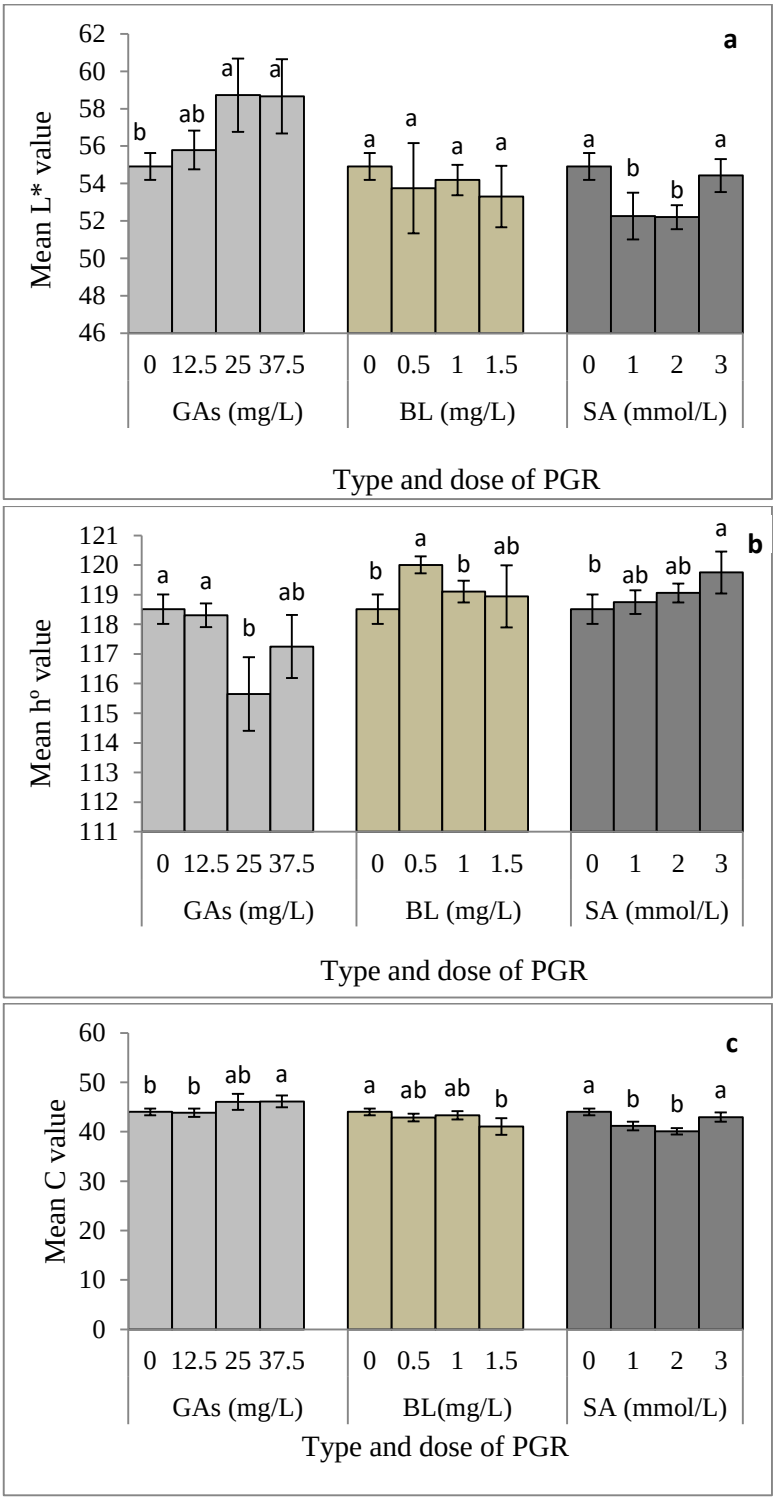
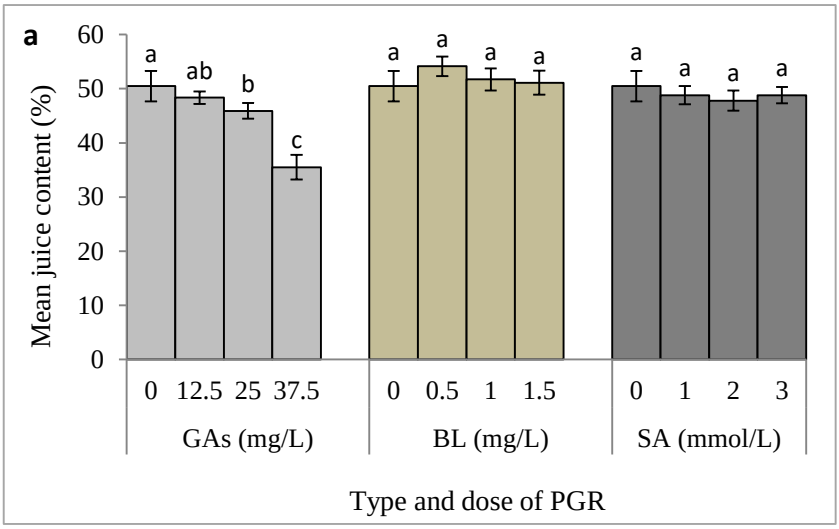


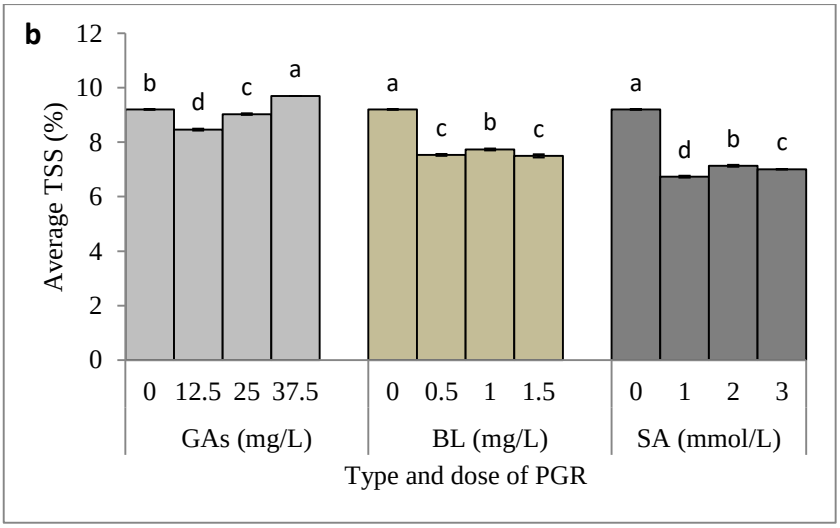
Fig. 3. Effect of gibberellic acid (GAs), brassinolide (BL) and salicylic acid (SA) on mean peel colour of lime fruit at optimum harvest maturity compared to the control fruit. Bars represent standard errors of the means, and values followed by different letters were significant according to chi-square test at $p < 0.05$. (n=60). L*: luminosity (0-black, 100-white), *C**: saturation, h^o: hue angle.

Juice content and its chemical quality

Percent juice content in control fruit was 50.5±2.8% and both BL and SA reported similar levels with no significant difference with the control (Fig. 4a). However, GA showed a remarkable reduction in fruit juice content and its effect was dose dependent of which when the concentration increased percent juice volume decreased. The highest (37.5 mg L-1), middle (25.0 mg L-1), and the lowest (12.5 mg L-1) doses of GA reduced the juice content by 15%, 5% and 2% respectively compared to the control.

TSS, TA and pH of lime fruit juice are shown in the Figures 4b, 4c and 4d respectively. SA and BL resulted in significantly lower TSS (Fig. 3b) while 37.5 mg L-1 of GA exhibited a significantly higher TSS compared to the control. However, TSS of fruit harvested from trees sprayed with other two doses of GAs (12.5 and 25.0 mg L-1) was lower than that of the control fruit significantly. Compared to the control, lower TA values were reported by SA treated fruit (Fig. 4c). On the contrary to TA, fruit that were treated by 12.5 and 37.5 mg L-1 of GA indicated significantly lower juice pH at their optimum harvest maturity (Fig. 4d). Treatment with BL resulted in significantly lower pH values. However, pH of the fruit received the lowest dose showed no significant difference with the control sample. Higher juice pH was reported by all three doses of SA compared to the control and the fruit sprayed with the lowest dose (1.0 mmol L-1) showed the highest (Fig. 4d) value.





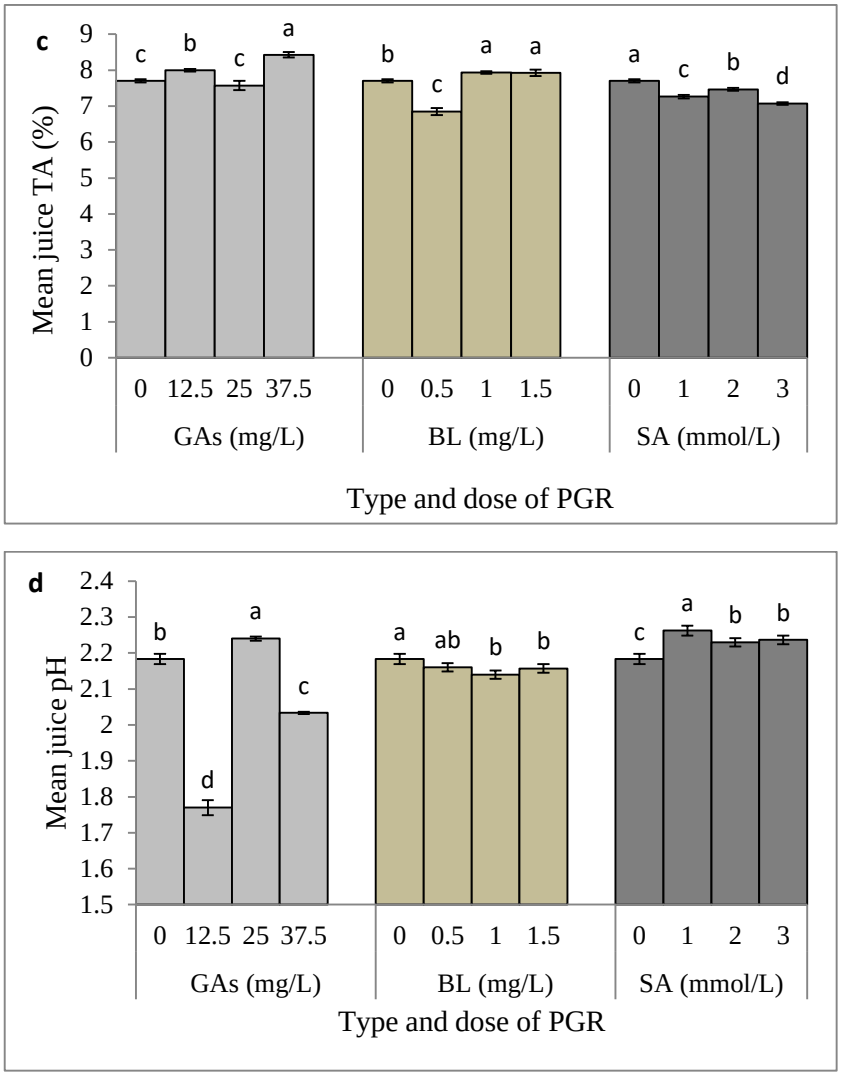


Fig. 4. Effect of gibberellic acid (GAs), brassinolide (BL) and salicylic acid (SA) on mean juice content (a), TSS (total soluble solids) (b), TA (titratable acidity) (c) and pH (d) of lime fruit at optimum harvest maturity compared to the control fruit. Bars represent standard errors of the means, and values followed by different letters were significance according to LSD at $p < 0.05$. (n=30 for the juice content and n=10 for the TSS, TA and pH)

DISCUSSION

Evidently, results of our study indicate that the acute seasonality in fruiting behaviour of acid limes (*C. aurantifolia*) could overcome by preharvest foliar treatment of GA, BL and SA. This is due to the differences in effects exerted by each hormone on cell division and elongation leading to either hasten or delay fruit maturity. Lime fruit is required to be on-tree for 5-months (147 days) to reach physiological maturity. Taking this as a benchmark, all three doses of both SA and BL hastened fruit maturity while GAs delayed it significantly.

Delayed fruit maturity by GA treatment (Fig. 1a and 1b) resulted in extending the normal harvest window that lies between mid-April to mid-July up to late-August. This could be corresponded to the delayed loss of peel greenness (Fig. 2 and 3) in response to applied GAs which regulates protein and nucleic acid synthesis thus retain chlorophyll moiety. As per the reports of Fletchner and Osborne (1965), Martfnez et al. (1996) and Tadeo et al. (2008) GA counteracts the rise of chlorophyllase which lead to retain chlorophyll pigments. In agreement with this; increased shoot length, leaf area and chlorophyll content over untreated plants of La

Conte pear was observed by Mosa et al. (2022). Symons et al. (2012) observed a decreased concentration of GA during the ripening phase of grapes suggesting that exogenous treatment of GAs during this period could delay the ripening. Observed dose dependent effect on delayed maturity in our study is consistent with previous reports on 'Ruby Red' grapefruit, 'Valencia' orange (Aluja et al., 2011) and 'Sunburst' mandarin (Pozo et al., 2000).

Two higher doses of GAs (25.0 and 37.5 mg L^{-1}) significantly improved fruit physical quality attributes (Table 1). The enhanced fruit size could be attributed to accelerated cell division & elongation (Samaradiwakara et al., 2020) by GA treatments applied at growth phases I (14 DAFS) and II (28-42 DAFS) of the acid lime (*C. aurantifolia*) fruit during the experimental period. Towards the maturity peel becomes thin, reducing peel: pulp ratio (Pozeo et al., 2000) and application of GAs retarded peel growth and aging in treated fruit resulting high peel thickness. Higher peel thickness and high firmness are important quality traits as the firmer fruits allow extended storage and tolerant to impact of handling during postharvest phase. Lower juice content, high TSS and TA observed with the highest dose of GA (Fig. 4b and 4c) could be due to the on-trees retention of fruit (187 days) compared to the control (147 days). It was resulted in lower juice volume (Fig. 4a) with high concentrations of TSS and TA. Similarly, application of GA has improved quality in 'Angelino' plums (Erogul & Sen, 2016) and Kinnow mandarin (Talat et al., 2020) which are non-climacteric fruits as acid limes.

In contrast to GA, advanced fruit maturity was occurred with BL treatment. The effect was dose dependent of which 0.5, 1.0 and 1.5 mg L^{-1} of BL shortened ($p<0.05$) the on-tree duration of fruit by 20 (~3 weeks), 27 (~1 month) and 75 (~2.5 months) days respectively (Fig. 1a and 1b). This resulted in advancing the harvest season to early-March. Endogenous BRs levels in non-climacteric and climacteric fruits remained high during cell division and elongation (Symons et al., 2012; Zhu et al., 2015), gradually declined and rose again near maturation and ripening phases. Hence, exogenous application of BL could increase the gene expression in BRs signalling pathway (Ayub et al., 2018) suggesting foliar applications performed at two phases of acid lime fruit growth in the present study may accelerate physiological process and complete subsequent phases of ontogeny well in advance. The dose dependent effect perceived in the present work agrees with Ayub et al. (2018) who observed that accumulation of BRs receptors accelerated the ripening of strawberries in response to exogenously applied BRs. BL treatment significantly improved fruit weight, diameter and length, enhancing visual appearance (Table 1 and Fig. 2). Improved growth parameters have been reported with foliar applied BRs in vegetables such as broccoli (Rastegar et al., 2022) and climacteric and non-climacteric fruits like tomato (Bhat et al., 2011), grapes (Champa et al., 2014) and sweet cherry (Roghabadi & Pakkish, 2010). With reference to biochemical properties, low TSS and pH alongside high TA observed in BL treated acid lime fruit could be due to advanced harvest date occurred because of treatment effect.

Similarly, application of SA hastened fruit maturity significantly ($p<0.05$) expanding the acute harvest season by ≈ 80 days (Fig. 1a and 1b). Accelerated fruit maturity when treated with SA has been reported for peach (Ali et al., 2021), grapes (Champa et al., 2015), strawberry (Karlidag et al., 2009) and tomato (Yildirim & Dursun, 2009). According to Mady (2009) SA treatment increased photosynthetic pigments and total carbohydrates. Moreover, Elwan & El-Hamahmy, (2009) observed enhanced translocation of sugars from leaves to fruit with SA treatments. These effects could be resulted in hastening maturity and improving fruit physical properties (Table 1, Fig. 2 and 3) observed in the present study. High peel thickness reported in SA treated fruit is an important quality trait which minimise handling damages and water loss during postharvest. Decreased TSS and TA alongside increased juice pH with SA treatment were observed by Champa et al. (2015) in grapes.

CONCLUSION

Lime fruit required 5 months' period from fruit set (147±1 days and 2332.6±10.6 GDDs) to reap quality attributes suitable for fresh market. Preharvest treatment of GAs with 25.0 and 37.5 mg L^{-1} enabled on-tree storage of lime fruit by 1 to 1.5 months respectively compared to the control. Foliar application of 1.5 mg L^{-1} BL and 1.0 mmol L^{-1} of SA advanced maturity by 75 and 80 days. However, considering the cost, treatment of SA twice at the rate of 1.0 mmol L^{-1} during cell division and cell enlargement phases of lime fruit could be recommended at farmer level to advance the maturity while GA at the rate of 37.5 mg L^{-1} could be recommended to delay harvesting. Altogether, the current acute fruit season which confined to four months could expand up to seven months. Findings of this study have significant practical applications in lime orchard management because split harvesting can be scheduled by applying above treatments into different paddocks.

Conflict of interest

The authors report there are no competing interests to declare.

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