Plant Archives Vol. 26, No. 1, 2026 pp. 2595-2600 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.1.360

INFLUENCE OF FOLIAR PLANT GROWTH REGULATORS AND MICRONUTRIENTS ON REPRODUCTIVE DYNAMICS, BIOCHEMICAL AND FRUIT QUALITY PARAMETERS IN ACID LIME CV. BALAJI

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(Date of Receiving-03-12-2025; Date of Revision-22-01-2026; Date of Acceptance-19-02-2026)

ABSTRACT

A field trial titled Influence of Foliar Plant Growth Regulators and Micronutrients on Reproductive Dynamics, Biochemical and Fruit Quality Parameters in Acid Lime cv. Balaji took place in 2024-25 at Jaggannapeta village, close to Dr. Y.S.R. Horticultural University in Andhra Pradesh. This research assessed how different foliar applications of plant growth regulators and micronutrients influenced flowering intensity, fruit characteristics and overall production. Employing a Randomized Block Design featuring three repeats and eight distinct treatments, notable differences emerged across the variables tested. The treatment GA_3 @ 50 ppm + $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6%) produced the highest fruit set per shoot (12.60), fruit weight (43.60 g), fruit diameter (4.80 cm), fruit volume (43.08 mL), chlorophyll content (61.00 SPAD), total sugars (1.90%), reducing sugars (0.92%) and non-reducing sugars (0.98%). It also resulted in the minimum peel thickness (2.10 mm). Meanwhile, 2,4-D @ 25 ppm with micronutrients showed the highest fruit retention (57.03%). The control treatment exhibited the poorest performance. Thus, GA_3 @ 50 ppm combined with micronutrients is recommended as the most effective treatment for enhancing flowering, fruit quality, and yield in acid lime cv. Balaji.

Key words : Acid lime, Balaji cultivar, Foliar micronutrients and PGR's.

Introduction

Citrus cultivation holds significant importance in tropical and subtropical areas, with India standing out as a leading producer. In 2023-24, citrus was grown across 336.29 thousand hectares, producing 2.81 million tonnes at a productivity rate of 8.36 MT/ha (NHB, 2024). Key varieties such as acid lime, lemon, mandarin, and sweet orange account for 12.4% of India's total fruit output. Andhra Pradesh and Gujarat dominate acid lime production, yielding 905.9 and 636.4 thousand tonnes, respectively (Sidhu, 2025).

Acid lime (*Citrus aurantifolia* Swingle), belonging to the Rutaceae family with 2n=18 chromosomes, is believed to have originated in tropical Asia. Prized for its flavorful, tangy fruits and therapeutic qualities, it holds the third position among India's citrus crops, following mandarin and sweet orange. The 'Balaji' acid lime variety, developed by Dr. YSR Horticultural University, Andhra Pradesh, is favoured for its superior traits (Reddy *et al.*, 2015). It yields 800-1200 fruits/tree annually, with medium-sized fruits featuring thin rind, high juice (45–50%), and acidity (6–7%), ideal for fresh use and processing. Early-bearing with uniform green-yellow fruits, it shows moderate tolerance to citrus canker and gummosis, plus long shelf life, transportability, and adaptability-making it suitable for commercial cultivation in Andhra Pradesh and Telangana.

Materials and Methods

The experiment took place in a 12-year-old acid lime orchard at a farmer's field in Jaggannapeta village, Tadepalligudem Mandal, West Godavari District, Andhra Pradesh, close to Dr. Y.S.R. Horticultural University, Venkataramannagudem. It followed a Randomized Block Design with eight treatments, each replicated three times using six trees per treatment. Forty-eight uniform trees, planted at 6 × 6 m spacing under consistent management and conditions, were chosen. Treatments comprised foliar sprays of GA_3 (50 ppm), NAA (100 ppm), 2,4-D (25 ppm), kinetin (50 ppm), salicylic acid (200 ppm), urea (2%) and KNO_3 (2%), each paired with $ZnSO_4$ (1%), $FeSO_4$ (1%) and borax (0.6%), plus a water-sprayed control. Data on flowering, fruit quality and yield were recorded and statistically analysed.

Preparation of Plant Growth Regulators and micro nutrients solutions

Stock solutions of plant growth regulators (GA_3, NAA, 2,4-D, kinetin and salicylic acid) were prepared by dissolving the required quantities in 5 mL absolute ethyl alcohol to ensure complete dissolution, followed by dilution to 1000 mL with distilled water in volumetric flasks. The concentrations prepared were GA_3 @ 50 ppm (50 mg/L), NAA @ 100 ppm (100 mg/L), 2,4-D @ 25 ppm (25 mg/L), kinetin @ 50 ppm (50 mg/L) and salicylic acid @ 200 ppm (200 mg/L).

Micronutrient and fertilizer solutions, including urea 2% (20 g/L), KNO_3 2% (20 g/L), $ZnSO_4$ 1% (10 g/L), $FeSO_4$ 1% (10 g/L) and borax 0.6% (6 g/L) were prepared by directly dissolving the weighed quantities in distilled water and making up the volume to 1000 mL. All solutions were mixed thoroughly to ensure uniformity before application.

Observations Recorded

For data collection, 20 shoots per tree were selected from four directions, tagged and used for recording flowering and fruiting parameters.

Reproductive parameters

Fruits set per shoot : Five shoots were randomly selected from each tree, covering all four sides, for recording fruit set. The initial number of fruits per shoot was counted on each selected shoot.

Fruit retention (%) : Fruit retention was determined by expressing the number of fruits remaining on the shoots as a percentage of the initial fruit set. The calculation used the following formula.

$$\text{Fruit retention}\left(\%\right)=\frac{\text{Number of fruits retained}}{\text{Number of fruits}}\times 100$$

Physical parameters : Five fruits selected on each random selected five branches of each treatment and tagged for recording various physical parameters.

Fruit diameter (cm) : The diameter of the fruits was measured from the centre of the fruits in centimetres at harvest with the help of digital Vernier Calipers.

Fruit volume (mL) : The volume of five randomly selected fruits was measured individually using the water displacement method. The average fruit volume for each treatment was then calculated and expressed in ml.

Peel thickness (mm) : Peel thickness was measured with the help of digital vernier callipers and expressed in millimeters (mm).

Bio-chemical parameters

Chlorophyll content in leaves (SPAD value) : Chlorophyll content in leaves was estimated using a SPAD chlorophyll meter by simply clamping the meter over the leaf tissue. This instrument works on the principle of measuring light absorbance by the leaf at two wavelengths.

Total sugars (%) : Total sugars were determined by the Lane-Eynon method (AOAC, 1965). Fifty milliliters of lead-free filtrate in a 100 mL volumetric flask was mixed with 5 mL concentrated HCl, kept for 24 hours at room temperature, neutralized with NaOH using phenolphthalein indicator, and made up to volume. The solution was titrated from a burette against standard Fehling's solution A: B (1:1) with methylene blue indicator until a brick-red endpoint.

$$\text{Total sugars}\left(\%\right)=\frac{\text{Factor}\times\text{Volume made up}}{\text{Titre value}\times\text{Weight of sample}}\times 100$$

Reducing sugars (%) : Reducing sugars in fruit juice were estimated by the Lane-Eynon method (AOAC, 1965). Ten mL juice was diluted to 250 mL with distilled water, treated with 2 mL each of 45% lead acetate and 22% potassium oxalate to remove colloids and excess lead, filtered lead-free and titrated from a burette against boiling 10 mL Fehling's solution (A: B, 1:1) using methylene blue indicator until a brick-red precipitate formed.

$$\text{Reducing sugars}\left(\%\right)=\frac{\begin{array}{c}\text{Factor for Fehling's solution}\\ \times\text{Total volume made up}\end{array}}{\text{Titre}\times\text{Weight of sample}}\times 100$$

Non-reducing sugars (%) : The percentage of non-reducing sugars was calculated by subtracting reducing sugars from total sugars using the following formula.

Non-reducing sugars (%) = Total sugars (%) – Reducing sugars (%)

Results and Discussion

The data presented in Tables 1, 2, 3, 4 and 5 results revealed that the fruit set per shoot, Fruit retention (%), fruit diameter, fruit volume, peel thickness, chlorophyll content in leaves, total sugars, reducing sugars and non-reducing sugars were significantly influenced by different concentrations of treatments.

Fruit set per shoot

Fruit set per shoot in acid lime cv. Balaji showed significant differences among treatments, with maximum values of 12.60 in T_1 (GA_3 @ 50 ppm + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%) and 11.80 in T_7 (KNO_3 2% + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%), versus minimum 6.00 in control T_8. GA_3 promotes cell elongation and reduces flower or fruit drop, zinc aids auxin synthesis and enzyme activation for reproduction, iron enhances chlorophyll and energy for flowering/fruit set and boron improves pollen germination and tube growth for better fertilization. These results align with Ramesh and Hegde (2018) in sweet lime, Deshmukh and Waghmare (2019) in Kagzi lime and Thakur *et al*. (2020) in custard apple.

Table 1 : Influence of foliar sprays on Fruit set per shoot and Fruit retention (%) in acid lime cv. Balaji.

Treatments	Fruit set per shoot	Fruit retention (%)
T_1 - GA_3 @ 50 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	12.60	57.03(49.02) *
T_2 - NAA @ 100 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	10.30	48.03(44.37) *
T_3 - 2,4-D @ 25 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	11.00	60.26(50.55) *
T_4 -Kinetin @ 50 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	9.46	47.43(44.00) *
T_5 -Salicylic acid @200 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	8.00	40.06(39.29) *
T_6 - Urea 2%+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	8.76	45.90(42.13) *
T_7 - KNO_3 2%+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	11.80	53.60(46.35) *
T_8 - Control (Water spray)	6.00	32.43(34.68) *
SEm(±)	**0.16**	**0.41**
CD at 5%	**0.50**	**1.27**

* Figures in parentheses indicate angular transformed values.

Table 2 : Influence of foliar sprays on fruit volume in acid lime cv. Balaji.

Treatments	Fruit volume (ml)
T_1 -GA_3 @ 50 ppm + $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	43.08
T_2 - NAA @ 100 ppm + $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6%)	39.32
T_3 -2,4-D @ 25 ppm + $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6%)	40.41
T_4 -Kinetin @ 50 ppm + $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6%)	37.17
T_5 -Salicylic acid @ 200 ppm + $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	36.45
T_6 - Urea 2%+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	38.45
T_7 - KNO_3 2%+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	41.67
T_8 -Control (Water spray)	34.26
SEm(±)	**0.08**
CD at 5%	**0.25**

Fruit retention percentage (%)

Fruit retention (%) showed significant treatment differences with maximum 60.26% in T_3 -2,4-D @ 25 ppm + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%) and 57.03% in T_1 - GA_3 @ 50 ppm + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%), versus minimum 32.43% in control T_8. This improvement stems from 2,4-D delaying abscission and ethylene production, $FeSO_4$ boosting photosynthesis, $ZnSO_4$ aiding auxin synthesis and borax enhancing pollen viability and carbohydrate transport for better fruit attachment. Findings align with Gaikwad *et al*. (2019) in pomegranate, Banday *et al*. (2020) in apple and Darshan *et al*. (2020) in kinnow mandarin**.**

Fruit volume (mL)

Fruit volume (mL) showed significant treatment differences in acid lime cv. Balaji, with maximum 43.08 mL in T_1 (GA_3 @ 50 ppm + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%) and 41.67 mL in T_7 (KNO_3 2% + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%), versus minimum 34.26 mL in control T_8. This increase results from GA_3

Table 3 : Influence of foliar sprays on fruit diameter (cm), peel thickness (mm) in acid lime cv. Balaji.

Treatments	Fruit diameter (cm)	Peel thickness (mm)
T_1 -GA_3 @ 50 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	4.80	2.10
T_2 - NAA @ 100 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	4.40	2.35
T_3 - 2,4-D @ 25 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	4.51	2.42
T_4 -Kinetin @ 50 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	4.19	2.28
T_5 -Salicylic acid @ 200ppm + $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	4.10	2.50
T_6 - Urea 2%+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	4.28	2.38
T_7 - KNO_3 2%+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	4.60	2.20
T_8 -Control (Water spray)	3.80	2.65
SEm(±)	**0.03**	**0.009**
CD at 5 %	**0.11**	**0.02**

Table 4 : Influence of foliar sprays on Chlorophyll content in leaves, total sugars, ascorbic acid in acid lime cv. Balaji.

Treatments	Chlorophyll content in leaves (SPAD value)	Total sugars (%)
T_1 -GA_3 @ 50 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	61.00	1.90(1.70) *
T_2 - NAA @ 100 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	57.50	1.72(1.64) *
T_3 - 2,4-D @ 25 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	54.50	1.77(1.66) *
T_4 -Kinetin @ 50 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	52.90	1.70(1.64) *
T_5 -Salicylic acid @ 200 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	51.46	1.60(1.60) *
T_6 - Urea 2%+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	56.00	1.68(1.63) *
T_7 - KNO_3 2%+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	59.00	1.85(1.68) *
T_8 - Control (Water spray)	49.13	1.51(1.57) *
SEm(±)	**0.18**	**0.009**
CD at 5 %	**0.56**	**0.02**

promoting cell elongation/division, zinc aiding auxin synthesis and enzymes, iron enhancing photosynthesis/ energy, and boron improving cell wall integrity and sugar translocation for better fruit enlargement. Findings agree with Dubey *et al*. (2015) in guava, Rani and Prasad (2016) in grapes and Shanker *et al*. (2019) in Kagzi lime.

Fruit diameter (cm)

Fruit diameter (cm) showed significant differences among treatments in acid lime cv. Balaji, with maximum 4.80 cm in T_1 (GA_3 @ 50 ppm + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%) and 4.60 cm in T_7 (KNO_3 2% + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%), versus minimum 3.80 cm in control T_8. This enhancement results from GA_3 stimulating cell elongation, zinc aiding auxin metabolism and enzymes, iron boosting chlorophyll/energy supply and boron supporting cell wall formation and sugar translocation for fruit expansion. Findings align with Gowda *et al*. (2016) in banana, Babu and Singh (2018) in mango and Patel *et al*. (2023) in Kagzi lime.

Peel thickness (mm)

Foliar sprays significantly affected peel thickness in acid lime cv. Balaji. The minimum (2.10 mm) occurred in T_1 (GA_3 @ 50 ppm + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%), followed by T_7 (KNO_3 2% + micronutrients; 2.20 mm), while the maximum (2.65 mm) was in T_8 (control). GA_3 and Kinetin reduced peel thickness by promoting pulp cell elongation and resource allocation to juice sacs, with micronutrients enhancing nutrient partitioning for better fruit quality. These results align with Singh *et al*. (2020) in acid lime, Hussain *et al*. (2022) in mung bean and Gao *et al*. (2023) in Kinnow mandarin.

Chlorophyll content in leaves (SPAD values)

Foliar treatments significantly influenced chlorophyll content (SPAD values) in acid lime cv. Balaji. The highest (61.00) was in T_1 (GA_3 @ 50 ppm + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%), followed by T_7 (KNO_3 2% + micronutrients; 59.00), with the lowest (49.13) in T_8 (control). This enhancement stems from GA_3 stimulating chlorophyll synthesis, zinc and iron acting as biosynthesis cofactors and boron aiding nutrient translocation- boosting photosynthetic efficiency and productivity. Findings align with Ilyas *et al*. (2015) in Kinnow and Yadav *et al*. (2017)

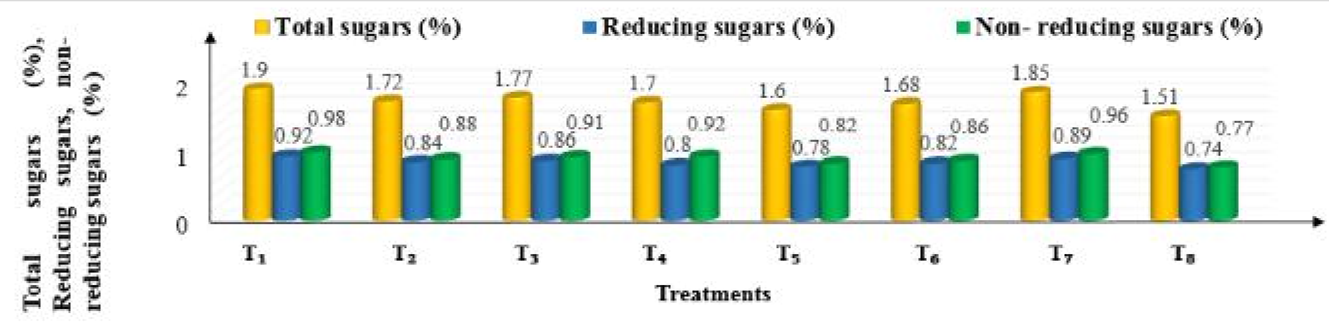

Fig. 1 : Influence of foliar sprays on total sugar, reducing sugars (%) and non-reducing (%) sugars in acid lime cv. BalajiSummary and conclusions.

Table 5 : Influence of foliar sprays on reducing sugars (%) and non-reducing (%) sugars in acid lime cv. Balaji.

Treatments	Reducing sugars (%)	Non-reducing sugars (%)
T_1 - GA_3 @ 50 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	0.92(1.38) *	0.98(1.40) *
T_2 - NAA @ 100 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	0.84(1.35) *	0.88(1.36) *
T_3 - 2,4-D @ 25 ppm+ $ZnSO_4$ (1%) + FeSO,, (1%) + borax (0.6 %)	0.86(1.36) *	0.91(1.39) *
T_4 -Kinetin @ 50 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	0.80 (1.34) *	0.92(1.38) *
T_5 -Salicylic acid @ 200 ppm+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	0.78(1.33) *	0.82(1.35) *
T_6 - Urea 2%+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	0.82(1.35) *	0.86(1.36) *
T_7 - KNO_3 2%+ $ZnSO_4$ (1%) + $FeSO_4$ (1%) + borax (0.6 %)	0.89(1.37) *	0.96(1.40) *
T_8 - Control (Water spray)	0.74(1.32) *	0.77 (1.32) *
SEm(±)	**0.004**	**0.003**
CD at 5%	**0.01**	**0.01**

in sweet orange.

Total sugars (%)

Foliar treatments significantly influenced total sugar content (%) in acid lime cv. Balaji. The highest (1.90%) was in T_1 (GA_3 @ 50 ppm + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%), followed by T_7 (KNO_3 2% + micronutrients; 1.85%), with the lowest (1.51%) in T_8 (control). GA_3 enhances photosynthate translocation to fruits, while Zn, Fe and B boost enzymatic activity and carbohydrate metabolism for better sugar accumulation. Similar results were reported by Kumar *et al*. (2015) in ber and Kumar *et al*. (2022) in strawberry.

Reducing sugars (%)

Foliar sprays significantly affected reducing sugar content in acid lime cv. Balaji. The highest (0.92%) was in T_1 (GA_3 @ 50 ppm + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%), followed by T_7 (KNO_3 2% + micronutrients; 0.89%), with the lowest (0.74%) in T_8 (control). GA_3 boosts photosynthate translocation, while micronutrients enhance enzymatic activity and carbohydrate metabolism for better sugar accumulation. Similar trends reported by Reddy *et al*. (2016) in pomegranate, Sharma *et al*. (2017) in grapes.

Non-reducing sugars (%)

Foliar sprays significantly affected non-reducing sugar content in acid lime cv. Balaji. The highest (0.98%) was in T_1 (GA_3 @ 50 ppm + $ZnSO_4$ 1% + $FeSO_4$ 1% + borax 0.6%), followed by T_7 (KNO_3 2% + micronutrients; 0.96%), with the lowest (0.77%) in T_8 (control). GA_3 stimulates sucrose synthesis and translocation, while Zn, Fe and B enhance carbohydrate metabolism and sugar transport, boosting fruit sweetness. Similar findings by Gaur *et al*. (2014) in mango and Kumbar *et al*. (2019) in sapota.

Summary and Conclusion

Foliar application of GA_3 (50 ppm) + $ZnSO_4$ (1%) + $FeSO_4$ (1%) + Borax (0.6%) T_1 significantly improved physical, reproductive and biochemical traits of acid lime, resulting in superior fruit quality, yield and economic returns. Hence, T_1 is recommended for achieving maximum productivity and profitability in acid lime cultivation.

Acknowledgement

The authors thank the College of Horticulture, Dr. Y.S.R. Horticultural University, Venkataramannagudem for financial support and providing facilities for conducting

of research.

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