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SECONDARY AND MICRONUTRIENT-MEDIATED RESPONSE OF GROWTH AND REPRODUCTIVE TRAITS IN PAPAYA CV. ARKA SURYA

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ABSTRACT

Papaya is an economically important tropical fruit crop valued for its high nutritional content, medicinal properties and year-round production potential. A field experiment was conducted at the Department of Fruit Science, College of Agriculture, Padannakkad, from November 2024 to November 2025 to study the effect of secondary and micronutrients supplementation on the growth and flowering attributes of papaya cv. Arka Surya. The experiment was laid out in a randomised block design with seven treatments and three replications. Foliar application of Micro sol (3%) and calcium nitrate (0.5%) given at 2nd, 4th, 6th and 8th months after planting (MAP) along with recommended dose of fertilizer (RDF) significantly enhanced vegetative growth in papaya, including plant height (233.91 cm), stem girth (37.08 cm) and leaf number (26.70) at 12 months after planting (MAP). Application of Ayar at 200 g during 2nd, 4th, 6th and 8th MAP along with RDF recorded highest percentage of female plants (77.77 %), fruit set percentage (84.10 %), while minimum height at first flowering (173.66 cm), less number of days to flowering (167.17 days), bisexual plants percentage (22.22 %), hermaphrodite flower percentage (10.91 %) and minimum days to harvest (221.55 days) compared to the control.

Keywords **:** Foliar, Sex expression, Supplementation, Traits, Vegetative.

Introduction

Papaya (*Carica papaya* L.) is an economically important tropical fruit crop belonging to the family Caricaceae, valued for its high nutritional, medicinal and industrial significance. The fruit is rich in vitamins A and C, minerals, dietary fibre and the proteolytic enzyme papain, which contribute to its nutraceutical importance. Owing to its rapid growth, precocious bearing, high yield potential and year-round fruiting habit, papaya has gained considerable commercial importance in tropical and subtropical regions. Although India is one of the leading producers of papaya, substantial regional disparities exist in productivity. In Kerala, despite considerable area under cultivation, productivity remains markedly low compared to the national average, mainly due to poor soil fertility, nutrient imbalances and inadequate crop management practices.

The predominantly lateritic soils of Kerala are acidic in nature and characterised by low nutrient availability, with widespread deficiencies of essential macronutrients, secondary nutrients and micronutrients. Deficiencies of calcium, magnesium, zinc, boron and copper are particularly common and adversely affect vegetative growth, flowering, fruit development and yield. Balanced nutrient management through secondary and micronutrient supplementation is therefore essential for improving papaya performance under Kerala conditions. In this regard, nutrient formulations developed by Kerala Agricultural University, *viz*., Micro sol and Ayar, offer effective potential for correcting nutrient deficiencies. Micro sol is a foliar micronutrient mixture containing iron (1 %),

zinc (2 %), copper (1 %), manganese (0.05 %), boric acid (1 %), ammonium molybdate (0.05 %) and organic acid (1 %) Ayar is a nutrient mixture that includes secondary nutrients such as calcium (15 %), magnesium (5 %) and sulphur (6 %), along with micronutrients like zinc (1.5 %) and boron (0.6 %) suited for soil application. Hence, the present investigation was undertaken with the objective of assessing the efficiency of secondary and micronutrient supplements in enhancing the growth and flowering parameters of papaya under the agro-climatic conditions of Kerala (Agro Ecological Unit-2).

Materials and Methods

The experiment was carried out at the Department of Fruit Science, College of Agriculture Padannakkad, during the period from November 2024 to November 2025 in the AEU 2 region (characterised by Sandy loam soil). The study was performed using Arka Surya, a gynodioecious papaya variety developed by the Indian Institute of Horticultural Research, Bangalore. Healthy seedlings of two-month-old plants raised in poly bags kept under a rain shelter were transplanted to the main field. The experimental field was laid out in a Randomised Block Design (RBD) consisting of seven treatments and three replications. In each replication, six plants were assigned to receive the same treatment. The crop was planted at 2 m × 2 m spacing. The following treatments, including T_1: Control (without any secondary and micronutrient spray), T_2: Micro sol 3 %, T_3: Micro sol 5 %, T_4: Micro sol 3 % + Ca $(NO_3)_2$ 0.5 %, T_5: Micro sol 5 % + Ca $(NO_3)_2$ 0.5 %, T_6: Ayar 100 g and T_7: Ayar 200 g. Organic manures (10 kg FYM plant^{-1}) and fertilizers (N: P_2O_5: K_2O at 40:40:80 g plant^{-1}) were applied to all plants uniformly as per the (KAU, 2024) recommendation for papaya, at bimonthly intervals up to 12 MAP. The treatments from T_2 to T_7 were applied at 2nd, 4th, 6th and 8th months after planting. Micro sol and calcium nitrate were administered as foliar sprays, whereas Ayar was applied directly to soil as plant base. Observations like plant height, stem girth, and number of fully expanded leaves were recorded at two-month intervals till 12 MAP. The height at first flowering was recorded as the distance from ground level to the node bearing the first flower. Days to first flowering were calculated as the number of days from transplanting to the opening of the first flower. Sex expression was determined by recording the number of bisexual and female plants in each replication and expressing them as percentages. The percentage of hermaphrodite flowers was calculated as the ratio of the number of hermaphrodite flowers to the total number of flowers produced per plant. Fruit set percentage was calculated by recording the number of fruits formed and the total number of flowers produced per plant and expressing the ratio as a percentage. The number of days to first harvest was recorded as the period from planting to the harvest of the first mature fruit for each observational plant and mean values were calculated (Anju, 2020).

Results and Discussion

Significant differences in plant height and collar girth were observed during the final growth phase, as depicted in Table 1. Among the treatments, T_4, a combined application of Micro sol (3 %) and calcium nitrate (0.5 %), recorded superior performance, indicating greater effectiveness in influencing these growth parameters. T_4 emerged as most effective, with the highest values for plant height (233.91 cm) and collar girth (37.08 cm) at 12 MAP. In contrast, T_1 (control) exhibited the lowest values for these parameters: plant height (208.87 cm) and girth (32.76 cm). Singh *et al.* (2018) reported that the combined application of copper sulphate (0.25 %), manganese sulphate (0.25 %), NAA (30 ppm) and GA_3 (60 ppm) resulted in the highest mean values for plant height (139.99 cm) and stem girth (42.69 cm) in the papaya variety Pusa Nanha. In addition, Mirza *et al.* (2023) reported that the application of $ZnSO_4$ (0.25 %) along with borax (0.50 %) improved the growth parameters such as plant height (209.78 cm) and plant girth (40.20 cm) for the papaya variety Red Lady at 270 days after planting. The treatment T_4 resulted in the highest number of leaves per plant (26.70), whereas control plants recorded the lowest leaf count (21.43). Premalatha *et al*. (2020) found that foliar spraying of micronutrient mixture (2 %) applied three times significantly increased leaf production in banana, with 11.67 leaves at four months after planting and 12.75 leaves at the shooting stage in banana cv. Nendran.

The findings of the study suggest that the application of optimum levels of micronutrients enhances plant height and stem thickness in papaya. Microsol consists of a balanced proportion of micronutrients such as iron, manganese, zinc, copper, boron and molybdenum. These micronutrients might play an important role in chlorophyll synthesis and active cell division, thereby promoting vegetative growth. In particular, zinc facilitates auxin biosynthesis, which further contributes to stem elongation and thickening. Thus, supplementation of micronutrients may enhance plant stability and might support more efficient translocation of nutrients within the plant system. The increase in leaf number may be attributed to the combined use of zinc and boron,

which aids the transport of carbohydrates such as starch and sugars across cell membranes. These micronutrients may also act as enzyme activators, thereby enhancing overall vegetative growth. Copper, in particular, may activate several enzymatic reactions, assists in chlorophyll synthesis, and contribute to carbohydrate and protein metabolism, all of which collectively supporting improved plant growth and development.

There was a significant difference in height at first flowering and days to flowering as presented in Table 4. T_1 (control) recorded the highest height at first flowering (197.82 cm), whereas the lowest height at first flowering was recorded in T_7: Ayar 200 g (173.66 cm) and T_4: Micro sol 3 % + Ca $(NO_3)_2$ 0.5 % (175.26 cm) among the treatments. Similarly, the control (190.82 days) exhibited a prolonged period for flowering compared to the other treatments. In contrast, the earliest flowering was noted in plants treated with T_7 (167.17 days) and T_4 (170.71 days). Similar findings were reported by Bindu (2019), that the Ayar treatment resulted in the earliest bunch emergence (190.56 days) in Nendran, whereas the control treatment showed a delayed bunch emergence (210.42 days). Kumar *et al.* (2024) reported that the highest plant height at first flowering (93.17 cm) was recorded in the application of borax 0.5 % and zinc sulphate 0.25 % at 60 and 120 DAP in the papaya variety Red Lady. The presence of boron and zinc in Ayar may enhance several key metabolic processes, including carbohydrate translocation, nitrogen assimilation, respiration, cell wall synthesis and RNA formation. These physiological changes may contribute to a reduction in plant height at the time of first flowering and promote earlier blooming. Boron, in particular, may stimulate the production of endogenous flowering substances such as florigen and accelerate floral initiation by shortening the vegetative phase, thereby potentially reducing the number of days required for first flowering in papaya. A comparatively reduced plant height at the stage of first flowering may be advantageous in papaya cultivation, as it can facilitate easier crop management and harvesting operations.

Assessment of sex expression in papaya showed that the cultivar Arka Surya expressed both female and bisexual plant types during the study. The highest proportion (77.77 %) of female plants was recorded in T_7 (Ayar 200 g), whereas T_1 recorded the lowest proportion of female plants (38.89 %). Conversely, the highest number of bisexual plants was recorded in T_1 (61.11 %), while T_7 showed the lowest (22.22 %). Comparable findings were recorded with respect to the percentage of hermaphrodite flowers. The highest proportion of hermaphrodite flowers (49.44 %) was observed in the T_1 (control), whereas the lowest proportion (10.91 %) was recorded in the T_7 (Ayar 200 g) treatment. The present results are consistent with the findings of Pant and Lavania (1998), who reported a significant increase in the proportion of female plants in papaya variety Pant Papaya-1 following foliar application of $ZnSO_4$ (0.15 %) combined with $FeSO_4$ (0.15 %). In addition, Anju *et al.* (2022) noted that foliar application of borax (0.5 %), zinc sulphate (0.5 %), along with calcium nitrate (0.5 %) applied at 4th and 7th MAP significantly increased the number of female plants compared to bisexual plants in the papaya variety Arka Surya.

Since Ayar contains boron, the increased proportion of female plants in papaya may be attributed to its role in enhancing indole acetic acid levels. Elevated levels of this hormone may promote femaleness and reduce the occurrence of hermaphrodite flowers. Moreover, improved root development in papaya can lead to increased cytokinin biosynthesis, which in turn promotes the expression of female characteristics in the plant. Studies have shown that female papaya plants possess higher concentration of cytokinins compared to hermaphrodite plants, which may contribute to reduction in the number of hermaphrodite flowers (Dhara and Veenranah, 2023).

The effect of different treatments on fruit set percentage showed that the treatments, T_7 (84.10 %) and T_4 (80.77 %) recorded the highest fruit set percentage, which were statistically on par, whereas the lowest fruit set was observed in T_1 (59.93 %). A similar trend was observed for days to first harvest. The earliest harvest was obtained in T_7 (221.55 days), which was also on par with T_4 (227.33 days), while T_1 required the longest duration (286.13 days) to attain the first harvest. Subedi *et al.* (2019) reported that the application of borax (0.3 %) and $ZnSO_4$ (0.2 %) in the papaya variety Red Lady significantly reduced the number of days to harvest, whereas the longest duration to harvest was recorded in the control and water spray treatments. In addition, Sebastian *et al.* (2021) observed that the highest fruit set (86.43 %) was recorded in plants receiving 100 % recommended dose of nitrogen and potassium through fertigation along with a foliar spray of 0.5 % zinc sulphate and 0.3 % borax in Arka Surya, whereas the control recorded the lowest fruit set (64.50 %) under bimonthly application.

Soil application of Ayar ensured a continuous supply of boron to the plant, which is essential for

pollen germination, pollen tube growth, and successful fertilisation. The presence of zinc further enhanced auxin biosynthesis, thereby preventing abscission and promoting fruit retention, which ultimately improved the fruit set percentage in papaya. In addition, calcium and magnesium contributed to strengthen the cell walls of the pollen tube and developing fruits, thereby reducing the fruit drop. Early maturity was also promoted through rapid cell division in young fruitlets immediately after fruit set, stimulated by zinc and boron, along with increased sugar accumulation in fruits. This, in turn, accelerated the transition from the growth phase to ripening (Patil *et al*., 2018).

Table 1 : Influence of secondary and micronutrient application on the plant height of papaya cv. Arka Surya

Treatment	Plant height (cm)					
	2MAP	**4MAP**	**6MAP**	**8MAP**	**10MAP**	**12MAP**
T_1	100.46	153.09^{d}	170.55^{d}	190.20^{d}	200.21^{d}	208.87^{d}
T_2	100.21	170.07^{abc}	192.04^{b}	201.30^{bc}	213.60^{bc}	220.21^{bc}
T_3	101.61	168.13^{bc}	189.99^{b}	197.20^{bcd}	211.19^{bc}	218.97^{bcd}
T_4	101.51	176.20^{a}	201.81^{a}	213.10^{a}	224.94^{a}	233.91^{a}
T_5	101.43	163.34^{c}	180.48^{c}	192.84^{cd}	204.10^{cd}	214.10^{cd}
T_6	103.22	171.39^{ab}	192.87^{ab}	204.50^{ab}	215.95^{ab}	225.51^{ab}
T_7	104.03	173.85^{ab}	197.13^{ab}	204.82^{ab}	214.13^{bc}	225.23^{abc}
SE (m) ±	2.45	2.60	2.91	3.47	3.31	3.65
CD @ 5 %	NS	8.02	8.97	10.69	10.19	11.24

Table 2 : Influence of secondary and micronutrient application on the plant girth of papaya cv. Arka Surya

Treatment	Plant girth (cm)					
	2MAP	**4MAP**	**6MAP**	**8MAP**	**10MAP**	**12MAP**
T_1	10.08	14.59^{c}	19.05^{d}	23.05^{c}	27.37^{e}	32.76^{c}
T_2	10.28	15.58^{bc}	20.60^{bc}	26.08^{ab}	31.24^{bc}	35.58^{ab}
T_3	10.59	15.13^{bc}	19.84^{cd}	25.57^{ab}	29.96^{cd}	34.26^{bc}
T_4	9.89	17.93^{a}	22.73^{a}	27.55^{a}	34.36^{a}	37.08^{a}
T_5	9.02	15.33^{bc}	19.73^{cd}	24.22^{bc}	29.10^{de}	33.97^{bc}
T_6	9.95	15.66^{bc}	21.57^{b}	26.60^{a}	32.11^{b}	35.95^{a}
T_7	9.57	16.04^{b}	21.02^{b}	26.85^{a}	31.80^{bc}	36.80^{a}
SE (m) ±	0.53	0.39	0.33	0.67	0.66	0.52
CD @ 5 %	NS	1.20	1.003	2.07	2.03	1.61

Table 3 : Influence of secondary and micronutrient application on the number of leaves of papaya cv. Arka Surya

Treatment	Number of leaves					
	2MAP	**4MAP**	**6MAP**	**8MAP**	**10MAP**	**12MAP**
T_1	11.01	13.12^{c}	14.55^{d}	15.77^{c}	18.14^{d}	21.43^{d}
T_2	11.29	16.41^{a}	18.01^{a}	20.36^{a}	22.49^{ab}	24.45^{b}
T_3	12.19	14.70^{b}	16.82^{bc}	19.29^{ab}	21.66^{bc}	24.01^{bc}
T_4	12.43	16.57^{a}	18.61^{a}	20.47^{a}	23.26^{a}	26.70^{a}
T_5	11.71	14.39^{b}	15.96^{c}	18.28^{b}	20.38^{c}	22.88^{c}
T_6	10.50	16.47^{a}	17.78^{ab}	19.56^{ab}	21.85^{ab}	24.44^{b}
T_7	10.98	16.32^{a}	17.96^{ab}	19.58^{ab}	22.06^{ab}	24.32^{b}
SE (m) ±	0.52	0.39	0.38	0.51	0.46	0.41
CD @ 5 %	NS	1.184	1.167	1.578	1.417	1.253

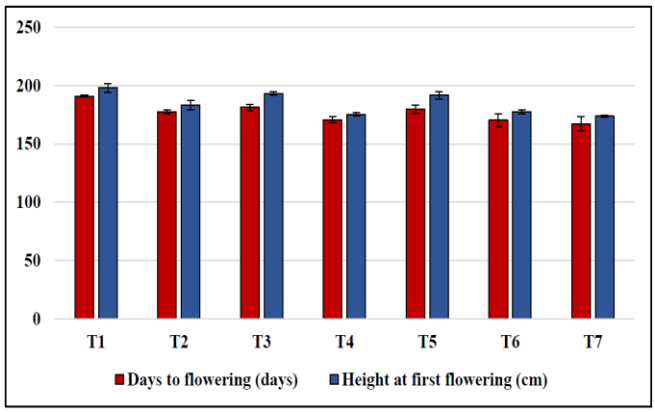

Fig. 1 : Influence of secondary and micronutrient application on the flowering characteristics of papaya

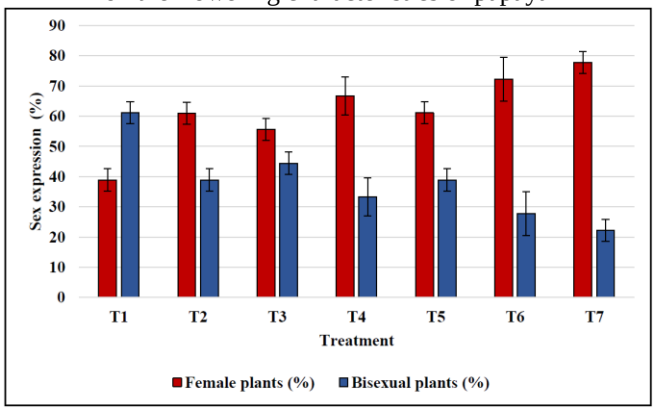

Fig. 2 : Influence of secondary and micronutrient application on sex expression of papaya

Table 4 : Influence of secondary and micronutrient application on fruit set percentage and days for first harvest of papaya.

Treatment	Percentage of hermaphrodite flowers (%)	Fruit set percentage (%)	Days for first harvest (Days)
T_1	49.44^{a}	59.93^{d}	286.13^{a}
T_2	27.85^{bc}	74.97^{bc}	234.55^{cd}
T_3	31.88^{b}	69.80^{c}	246.61^{bc}
T_4	19.88^{bcd}	80.77^{ab}	227.33^{cd}
T_5	24.80^{bcd}	71.70^{c}	257.94^{b}
T_6	13.78^{cd}	82.47^{ab}	226.93^{cd}
T_7	10.91^{d}	84.10^{a}	221.55^{d}
SE(m) ±	4.63	2.73	7.44
CD @ 5 %	14.25	8.40	22.93

Conclusion

The present investigation conducted at Kerala Agricultural University to evaluate the influence of secondary and micronutrient supplementation on the growth and flowering behaviour of papaya cv. Arka Surya demonstrated the significant role of balanced nutrient management in enhancing crop performance. The results revealed that the foliar application of Micro sol (3%) in combination with calcium nitrate (0.5%) at 2, 4, 6 and 8 months after planting (MAP), along with the recommended dose of fertilizers (RDF), markedly improved vegetative growth attributes such as plant height, stem girth and number of leaves. This treatment was followed by the application of Ayar at 200 g plant^{-1} and 100 g plant^{-1}, indicating their positive influence on vegetative development under the agro-ecological conditions of AEU-2 of Kerala.

Regarding reproductive performance, the application of Ayar at 200 g plant^{-1} at 2, 4, 6 and 8 MAP along with RDF recorded superior results for flowering and related reproductive parameters and was found to be statistically on par with the Micro sol (3%) and calcium nitrate (0.5%) treatment. The findings highlight that supplementation of secondary and micronutrients in addition to the recommended nutrient schedule effectively promotes both vegetative vigour and reproductive efficiency in papaya.

Therefore, the study concludes that the integration of appropriate secondary and micronutrient sources with the recommended application of farmyard manure (FYM) and NPK fertilizers, as prescribed in the KAU Package of Practices, can substantially enhance growth, flowering and overall productivity of papaya cv. Arka Surya grown under the sandy loam soil conditions of AEU-2 region of Kerala. The adoption of these nutrient management practices may contribute to improved crop performance and sustainable papaya production in similar agro-climatic regions.

Author's Contribution

Conceptualisation of research (MMN, SNS, BNK, MMV); Design of the experiments (AA, MMN); Execution of field/lab experiments and data handling (AA); Analysis of data and interpretation (AA, MMN, SNS); Preparation of the manuscript (AA); Review and editing (MMN, SNS)

Declaration

The authors declare no conflict of interest.

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