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EFFECT OF GROWTH REGULATORS, MICRONUTRIENTS AND BIOMIX ON PLANT GROWTH, FRUIT DROP, YIELD AND QUALITY OF MANDARIN (*Citrus reticulata* L.) CV. NAGPUR SANTRA

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ABSTRACT

A field experiment was conducted during *Ambe bahar* 2025–26 at Jamb village, near Parbhani, Maharashtra, to evaluate the effect of growth regulators, micronutrients and Biomix on plant growth, fruit drop, yield and quality of Nagpur mandarin (*Citrus reticulata* L.). The experiment was laid out in a randomized block design with fifteen treatments, comprising $ZnSO_4$, $FeSO_4$, $CuSO_4$, NAA and 2,4-D with Biomix at 0.1% and 0.2% along with an untreated control, replicated twice. Treatment T_{14} ($ZnSO_4$ 0.5% + $FeSO_4$ 0.5% + $CuSO_4$ 0.5% + 2,4-D 10 ppm + NAA 10 ppm + Biomix 0.2%) recorded the maximum incremental plant height (20.70 cm), stem diameter (0.88 cm) and number of branches (12.60), the highest fruit set (66.86%) and the lowest fruit drop (35.32%), and the highest yield per plant (32.88 kg) and per hectare (91.33 q) as against 13.27 cm, 0.55 cm, 6.10, 52.16%, 53.19%, 17.18 kg and 47.72 q, respectively, in the control. T_{14} also gave the best fruit juice content (52.08%), TSS (12.58 °Brix), TSS : acid ratio (19.21), ascorbic acid (29.60 mg/100 g), the lowest acidity (0.65%), and the highest benefit : cost ratio (2.59) against 1.53 in the control. T_{14} was followed closely by T_{13}, T_7 and T_6. Integrated foliar application of micronutrients and growth regulators with Biomix @ 0.2% (T_{14}) is therefore recommended for mandarin under Marathwada conditions, subject to confirmation over more seasons and locations.

***Key words*:** Mandarin, Growth regulators, Micronutrients, Biomix, Fruit drop.

Introduction

Mandarin (*Citrus reticulata* L.) belongs to the family Rutaceae and is one of the most widely cultivated and economically important fruit crops of the world, valued for its easy peeling, attractive colour, aroma and a well-balanced sugar–acid ratio, besides being rich in vitamin C, flavonoids and dietary fibre (FAO, 2022). India ranks among the top five mandarin-producing countries and mandarin holds the top position among its citrus fruits, with Nagpur mandarin ('Nagpur Santra') the most famous variety for its quality, deep orange colour and high juice content (NHB, 2022; ICAR–CCRI, 2021). Maharashtra is the leading mandarin-growing state, with major concentration in the Vidarbha and Marathwada regions, where orchards are managed mainly under *ambe bahar* and *mrig bahar* (ICAR–CCRI, 2021). However, productivity remains low owing to erratic flowering, heavy fruit drop, nutritional deficiencies, moisture stress and poor post-harvest handling (Sharma *et al*., 2019).

Fruit drop, occurring at the flowering, pea and marble stages, is one of the most serious problems and is governed by hormonal imbalance, particularly the auxin–ethylene ratio, together with nutritional deficiencies and adverse environmental conditions (Randhawa, 1985;

Monselise, 1979). Growth regulators such as NAA and 2,4-D inhibit abscission-layer formation and improve fruit retention, fruit size and yield (Bons and Kaur, 2020; Kaur and Bal, 2017; Srivastava and Singh, 2016). Micronutrients such as zinc, iron and copper play vital roles in enzymatic reactions, photosynthesis and reproductive development, but the soils of the citrus belts of Vidarbha and Marathwada are often deficient in them (Chapman, 1968), and foliar application is an effective means of correcting the deficiency (Chandra *et al*., 2020). Kale *et al*. (2022) reported the highest fruit number and yield with integrated application of zinc, iron and copper sulphates with NAA and Biomix.

Biomix, a consortium of beneficial microorganisms including nitrogen-fixing and phosphate-solubilizing bacteria and plant growth-promoting rhizobacteria, enhances nutrient availability and root growth (Vessey, 2003), and improved canopy spread, fruit weight, juice percentage and ascorbic acid content in earlier studies on mandarin (Verma and Yadav, 2017; Pawar *et al*., 2021). Scientific information on the integrated use of growth regulators, micronutrients and Biomix under Marathwada conditions is, however, limited. The present investigation was therefore undertaken during *ambe bahar* 2025–26:

(i) to study the influence of these treatments on growth parameters and fruit yield of mandarin and

(ii) to assess their impact on fruit retention and quality.

Materials and Methods

Experimental site and climate

The experiment was conducted during *Ambe bahar* 2025–26 in an orchard at Jamb village, near Parbhani, under Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani. Parbhani is situated at 19°16’ N latitude and 76°47’ E longitude at an altitude of about 409 m above mean sea level, with a semi-arid tropical climate, summer maximum temperature of 42–45 °C, winter minimum of 10–12 °C and average annual rainfall of 850–900 mm, received mostly during June–September. The soil is medium black, with high clay content, pH 7.5 to 8.2, low to medium organic carbon (0.3–0.6%) and is often deficient in zinc, iron and copper.

Experimental design and treatments

The experiment was laid out in a randomized block design (RBD) with fifteen treatments and two replications, with two plants per treatment (60 plants in all), on seven-year-old Nagpur Santra trees planted at 6.0 × 6.0 m. The treatments are given in Table 1. Micronutrients and growth regulators were applied as foliar sprays at two stages, full bloom and the pea-sized fruit stage, early in the morning until the leaves were completely wetted, using a knapsack sprayer. Zinc, ferrous and copper sulphates were used at 0.5% (5 g per litre). NAA and 2,4-D were first dissolved in ethanol and then made up with clean water. Biomix (1 g and 2 g per litre for 0.1% and 0.2%, respectively) was applied as a soil drench around the root zone at the same two stages.

Observations recorded

Incremental plant height, canopy spread (N–S and E–W), stem diameter (girth at 15–20 cm above ground level) and number of branches were recorded before treatment and at the final stage. Total number of flowers was counted on tagged branches at peak flowering and extrapolated per plant, fruit set (%) was recorded 30 days after full bloom, and fruit drop (%) was worked out as the number of fruits dropped before harvest in relation

Table 1: Treatment details.

Treatment No.	Treatment details
T_1	$ZnSO_4$ 0.5% + NAA 10 ppm + Biomix 0.1%
T_2	$FeSO_4$ 0.5% + NAA 10 ppm + Biomix 0.1%
T_3	$CuSO_4$ 0.5% + NAA 10 ppm + Biomix 0.1%
T_4	2,4-D 20 ppm + NAA 10 ppm + Biomix 0.1%
T_5	$ZnSO_4$ 0.5% + $FeSO_4$ 0.5% + NAA 10 ppm + Biomix 0.1%
T_6	$ZnSO_4$ 0.5% + $FeSO_4$ 0.5% + $CuSO_4$ 0.5% + NAA 10 ppm + Biomix 0.1%
T_7	$ZnSO_4$ 0.5% + $FeSO_4$ 0.5% + $CuSO_4$ 0.5% + 2,4-D 10 ppm + NAA 10 ppm + Biomix 0.1%
T_8	$ZnSO_4$ 0.5% + NAA 10 ppm + Biomix 0.2%
T_9	$FeSO_4$ 0.5% + NAA 10 ppm + Biomix 0.2%
T_{10}	$CuSO_4$ 0.5% + NAA 10 ppm + Biomix 0.2%
T_{11}	2,4-D 20 ppm + NAA 10 ppm + Biomix 0.2%
T_{12}	$ZnSO_4$ 0.5% + $FeSO_4$ 0.5% + NAA 10 ppm + Biomix 0.2%
T_{13}	$ZnSO_4$ 0.5% + $FeSO_4$ 0.5% + $CuSO_4$ 0.5% + NAA 10 ppm + Biomix 0.2%
T_{14}	$ZnSO_4$ 0.5% + $FeSO_4$ 0.5% + $CuSO_4$ 0.5% + 2,4-D 10 ppm + NAA 10 ppm + Biomix 0.2%
T_{15}	Control

Table 2: Effect of growth regulators, micronutrients and Biomix on plant growth of mandarin.

Treatments	IPH	ICS	ICW	ISD	NB
T_1	16.50	18.12	17.13	0.72	9.05
T_2	15.92	16.82	15.93	0.67	8.28
T_3	14.86	15.52	14.74	0.62	7.70
T_4	13.80	14.22	13.54	0.57	6.83
T_5	18.05	19.41	18.32	0.76	9.85
T_6	19.11	20.71	19.52	0.81	10.55
T_7	19.64	21.36	20.12	0.83	11.20
T_8	17.52	18.76	17.72	0.74	9.48
T_9	16.45	17.47	16.53	0.69	8.70
T_{10}	15.39	16.17	15.33	0.64	8.03
T_{11}	14.33	14.87	14.14	0.60	7.33
T_{12}	18.58	20.06	18.92	0.79	10.30
T_{13}	20.17	22.01	20.72	0.86	11.85
T_{14}	20.70	22.66	21.32	0.88	12.60
$T_{15(control)}$	13.27	13.57	12.95	0.55	6.10
S.Em±	1.22	1.43	1.35	0.03	0.74
CD at 5%	3.71	4.35	4.09	0.11	2.25

IPH: Incremental plant height (cm); ICS: Incremental canopy spread N–S (cm); ICW: Incremental canopy spread E–W (cm); ISD: Incremental stem diameter (cm); NB: Number of branches

to the initial fruit set. Number of fruits, fruit weight and yield per plant were recorded at harvest and yield per hectare was calculated from the spacing. Fruit length, breadth and volume (water displacement), rind thickness, and juice, rind and pomace percentages were measured on ten fruits per plant. TSS was measured with a hand refractometer, reducing and total sugars by Benedict's quantitative reagent method, acidity by titration with standard NaOH, and ascorbic acid by the 2,6-dichlorophenol indophenol method. The benefit: cost ratio was worked out as net profit divided by the total cost of cultivation.

Statistical analysis

The data were subjected to analysis of variance for RBD (Panse and Sukhatme, 1985). Treatment differences were tested by the F-test at 5% level of probability, and critical difference (CD) at 5% was calculated wherever the F-test was significant.

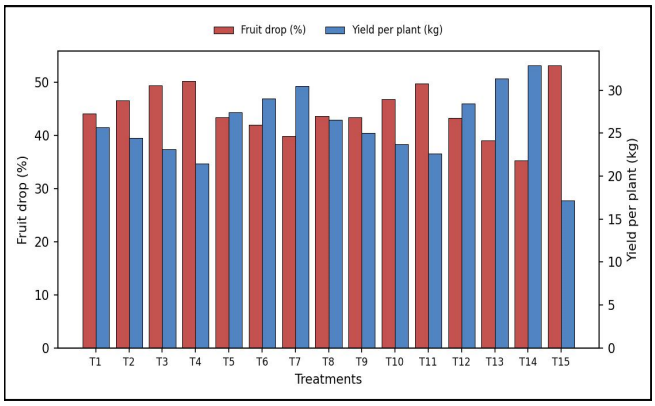


Fig. 1: Effect of growth regulators, micronutrients and Biomix on fruit drop (%) and yield per plant (kg) of mandarin.

Table 3: Effect of growth regulators, micronutrients and Biomix on flowering, fruit set and fruit drop of mandarin.

Treatments	TNF	FS	FD	FR
T_1	442.50	60.47	44.10	55.90
T_2	456.50	58.63	46.56	53.44
T_3	477.00	56.62	49.44	50.60
T_4	474.50	55.38	50.26	49.74
T_5	442.50	62.40	43.42	56.58
T_6	434.50	64.37	42.00	58.00
T_7	428.50	64.43	39.89	60.11
T_8	444.00	61.23	43.69	56.31
T_9	433.00	59.62	43.42	56.58
T_{10}	457.50	57.73	46.82	53.18
T_{11}	474.00	56.19	49.80	50.20
T_{12}	439.50	63.77	43.27	56.73
T_{13}	418.50	65.58	39.04	60.96
T_{14}	394.50	66.86	35.32	64.68
$T_{15(control)}$	462.50	52.16	53.19	46.81
S.Em±	13.28	1.60	2.40	2.40
CD at 5%	40.68	4.80	7.30	7.30

TNF: Total number of flowers; FS: Fruit set (%); FD: Fruit drop (%); FR: Fruit retention (%)

Results and discussion

Plant growth

Treatment T_{14} recorded the maximum incremental plant height (20.70 cm), which was at par with T_{13} (20.17 cm), T_7, T_6, T_{12} and T_5, whereas the minimum (13.27 cm) was in the control (Table 2). The incremental canopy spread was also maximum in T_{14} (22.66 cm N–S and 21.32 cm E–W) against 13.57 and 12.95 cm in the control. T_{14} recorded the significantly highest incremental stem diameter (0.88 cm) and number of branches (12.60) against 0.55 cm and 6.10 in the control.

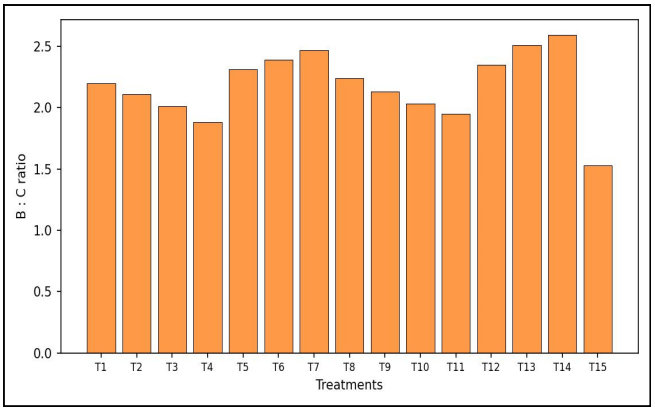


Fig. 2: Effect of growth regulators, micronutrients and Biomix on benefit : cost ratio of mandarin.

Table 4: Effect of growth regulators, micronutrients and Biomix on yield and yield attributes of mandarin.

Treatments	NFPP	FW	YPP	YPH
T_1	149.50	172.10	25.64	71.23
T_2	143.00	170.97	24.45	67.91
T_3	137.00	168.92	23.14	64.28
T_4	131.00	163.78	21.46	59.61
T_5	156.50	175.97	27.45	76.25
T_6	162.00	179.00	29.00	80.56
T_7	165.00	184.75	30.48	84.68
T_8	153.50	173.60	26.56	73.79
T_9	146.00	171.32	25.01	69.47
T_{10}	140.00	169.60	23.74	65.95
T_{11}	134.50	168.72	22.61	62.81
T_{12}	159.50	178.90	28.44	79.00
T_{13}	167.00	186.42	31.32	87.00
T_{14}	171.50	192.27	32.88	91.33
$T_{15(control)}$	113.00	152.07	17.18	47.72
S.Em±	5.03	4.86	1.36	4.06
CD at 5%	15.11	14.61	4.11	12.23

NFPP: Number of fruits per plant; FW: Fruit weight (g); YPP: Yield per plant (kg); YPH: Yield per hectare (q)

The improved vegetative growth may be attributed to the role of zinc and iron in chlorophyll formation, photosynthesis and enzyme activity, of NAA and 2,4-D in cell division and elongation, and of Biomix in improving nutrient availability and uptake. Similar trends were reported by Prasad *et al.*, (2013) in Kinnow mandarin, Ram and Bose (2000) for canopy development in mandarin, and Tsomu and Patel (2019) in mango and Vikas and Verma (2017) in guava.

Flowering, fruit set and fruit drop

The total number of flowers per plant was lowest in T_{14} (394.50) and highest in T_3 (477.00), the control recording 462.50 (Table 3). Since the first spray was given at full bloom, this reflects a mild thinning action of NAA and 2,4-D on weaker flowers, as reported by Vashisth *et al.*, (2025) and Garmendia *et al.*, (2019). Despite this, T_{14} recorded the highest fruit set (66.86%) and the lowest fruit drop (35.32%), with the highest fruit retention (64.68%), and was at par with T_{13} (39.04% drop), T_7 (39.89%) and T_6 (42.00%). The control recorded the lowest fruit set (52.16%) and the highest fruit drop (53.19%).

Auxins delay abscission-layer formation by suppressing ethylene synthesis and the activity of cell-wall degrading enzymes, while zinc, iron and Biomix improve carbohydrate supply and plant vigour. Prasad *et al.*, (2023) reported a significant reduction in fruit drop with 2,4-D, urea and zinc sulphate in Kinnow mandarin, and Ruchal *et al.*, (2020) improved fruit setting in mandarin with foliar zinc and boron.

Yield and yield attributes

T_{14} recorded the highest number of fruits per plant (171.50), fruit weight (192.27 g), yield per plant (32.88 kg) and yield per hectare (91.33 q), at par with T_{13} (31.32 kg per plant; 87.00 q ha^{-1}), T_7 and T_6, against 113.00 fruits, 152.07 g, 17.18 kg and 47.72 q ha^{-1} in the control

Table 5: Effect of growth regulators, micronutrients and Biomix on fruit physical characters of mandarin.

Treatments	Fruit length (cm)	Fruit breadth (cm)	Fruit volume (cc)	Rind thickness (mm)	Rind (%)	Pomace (%)	Juice (%)	Number of seeds per fruit	Seed weight (g)
T_1	5.94	6.24	181.07	3.33	28.76	27.86	43.38	4.75	0.91
T_2	5.78	6.10	179.47	3.43	29.15	29.11	41.74	5.25	0.91
T_3	5.62	5.96	176.55	3.55	29.51	30.37	40.12	5.25	0.90
T_4	5.44	5.93	172.60	3.65	29.58	31.62	38.80	5.25	0.89
T_5	6.10	6.38	182.67	3.16	27.89	26.60	45.51	4.75	0.90
T_6	6.26	6.52	188.00	3.12	26.95	25.35	47.70	5.50	0.88
T_7	6.44	6.67	193.45	3.11	25.60	24.72	49.68	4.75	0.87
T_8	6.02	6.31	182.27	3.23	28.70	27.23	44.07	4.25	0.90
T_9	5.86	6.17	180.37	3.38	28.82	28.48	42.70	5.70	0.91
T_{10}	5.70	6.03	177.19	3.49	29.25	29.74	41.01	5.00	0.91
T_{11}	5.54	5.89	174.77	3.59	29.42	30.99	39.59	4.75	0.90
T_{12}	6.18	6.45	183.82	3.15	27.68	25.98	46.34	5.50	0.89
T_{13}	6.47	6.70	199.15	3.01	24.77	24.10	51.13	4.50	0.88
T_{14}	6.50	6.73	203.55	2.51	24.45	23.47	52.08	4.50	0.86
$T_{15(control)}$	5.33	5.82	161.10	4.11	30.13	32.26	37.61	5.00	0.93
S.Em±	0.10	0.70	5.41	0.18	0.88	0.84	1.12	0.65	0.010
CD at 5%	0.32	0.22	16.43	0.56	2.70	2.54	3.42	NS	NS

Table 6: Effect of growth regulators, micronutrients and Biomix on chemical quality of mandarin.

Treatments	TB	RS	NRS	TS	AD	AR	AA
T_1	11.57	3.23	4.26	7.49	0.79	14.55	27.02
T_2	11.52	3.09	4.19	7.28	0.82	14.04	26.73
T_3	11.35	3.06	4.11	7.17	0.84	13.77	26.67
T_4	11.11	2.99	3.90	6.80	0.87	12.70	24.41
T_5	11.81	3.43	4.40	7.84	0.77	15.33	27.12
T_6	11.97	3.50	4.49	7.98	0.73	16.29	28.00
T_7	12.10	3.52	4.51	8.03	0.71	16.93	28.30
T_8	11.69	3.38	4.35	7.73	0.78	14.90	27.10
T_9	11.56	3.20	4.23	7.43	0.81	14.27	26.82
T_{10}	11.40	3.09	4.13	7.22	0.83	13.73	26.69
T_{11}	11.21	3.18	4.07	7.26	0.85	13.18	25.57
T_{12}	11.93	3.44	4.42	7.87	0.75	15.80	28.29
T_{13}	12.19	3.61	4.60	8.21	0.69	17.54	29.52
T_{14}	12.58	3.75	4.75	8.50	0.65	19.21	29.60
$T_{15(control)}$	10.52	2.83	3.70	6.53	0.88	11.95	24.13
S.Em±	0.23	0.11	0.10	0.19	0.017	0.59	0.76
CD at 5%	0.73	0.35	0.31	0.60	0.058	1.78	2.33

TB:TSS (°Brix); RS: Reducing sugars (%); NRS: Non-reducing sugars (%); TS: Total sugars (%); AD: Acidity (%); AR: TSS : acid ratio; AA: Ascorbic acid (mg/100 g juice)

(Table 4). The superiority of T_{14} was due to better fruit retention, reduced fruit drop and improved fruit development under the combined action of micronutrients, auxins and Biomix. The results agree with Ahmad *et al.*, (2008) in Kinnow mandarin, Yadav *et al.*, (2026), Srivastava and Singh (2011) in Nagpur mandarin and Tsomu and Patel (2019) in mango.

Fruit physical characters

T_{14} recorded the highest fruit length (6.50 cm), breadth (6.73 cm), volume (203.55 cc) and juice percentage (52.08%), and the lowest rind thickness (2.51 mm), rind percentage (24.45%) and pomace percentage (23.47%), all significantly superior to the control (5.33 cm, 5.82 cm, 161.10 cc, 37.61%, 4.11 mm, 30.13% and 32.26%, respectively) (Table 5). Number of seeds per fruit (4.25–5.70) and seed weight (0.86–0.93 g) were non-significant, indicating that seed traits are governed largely by genetic and pollination factors (Garmendia *et al.*, 2022; Gonzatto *et al.*, 2022). The improvement in the other characters agrees with Ram and Bose (2000), Yadav *et al.*, (2026), Deshmukh *et al.*, (2016) in acid lime and Bhite *et al.*, (2017) in sweet orange.

Chemical quality

T_{14} recorded the highest TSS (12.58 °Brix), reducing sugars (3.75%), non-reducing sugars (4.75%), total sugars (8.50%), TSS : acid ratio (19.21) and ascorbic acid (29.60 mg/100 g juice), and the lowest acidity (0.65%), against 10.52 °Brix, 2.83%, 3.70%, 6.53%, 11.95, 24.13 mg and 0.88% in the control (Table 6). Zinc is a co-factor of carbohydrate-metabolizing enzymes, and auxins promote translocation of photosynthates to the developing fruit, favouring accumulation of sugars and utilization of organic acids. Similar results were reported by Gurjar *et al.*, (2018), Razzaq *et al.*, (2013), Kaur *et al.*, (2015) and Yadav *et al.*, (2026) in Kinnow mandarin, and Bhowmick *et al.*, (2012) in mango.

Table 7: Effect of growth regulators, micronutrients and Biomix on benefit : cost ratio of mandarin.

Treatments	B : C ratio
T_1	2.20
T_2	2.11
T_3	2.01
T_4	1.88
T_5	2.31
T_6	2.39
T_7	2.47
T_8	2.24
T_9	2.13
T_{10}	2.03
T_{11}	1.95
T_{12}	2.35
T_{13}	2.51
T_{14}	2.59
$T_{15(control)}$	1.53
S.Em±	–
CD at 5%	–

Economics

The benefit: cost ratio ranged from 1.53 in the control to 2.59 in T_{14}, followed by T_{13} (2.51), T_7 (2.47) and T_6 (2.39) (Table 7). The additional cost of micronutrients, growth regulators and Biomix was more than compensated for by the increase in yield and quality, in agreement with Razzaq *et al.*, (2013) and Meena *et al.*, (2021).

Conclusion

Integrated foliar application of $ZnSO_4$ 0.5% + $FeSO_4$ 0.5% + $CuSO_4$ 0.5% + 2,4-D 10 ppm + NAA 10 ppm with Biomix @ 0.2% (T_{14}) was the best treatment, recording the highest growth, fruit set, yield, fruit quality and benefit : cost ratio and the lowest fruit drop, followed by T_{13}, T_7 and T_6. The control was the poorest for most parameters. Since the study was conducted for one season at one location, it should be repeated to confirm the consistency of the findings.

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