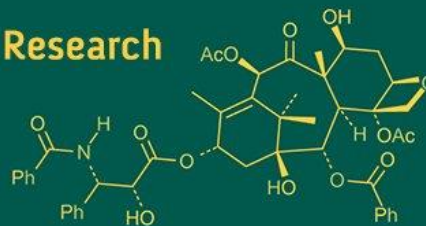


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Effect of plant growth substances on growth and yield of Nagpur mandarin

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Abstract

A field experiment was conducted to evaluate the influence of various plant growth substances on the vegetative growth, floral parameters, yield performance and economics of eighteen-year-old Nagpur mandarin (*Citrus reticulata* Blanco) trees. Based on the pooled data, major vegetative parameters namely, plant height, canopy spread and canopy volume statistically found non significant by the exogenous application of growth substances. However, the pooled leaf area showed a maximum (45.39 cm²) recorded in trees subjected to Treatment 7 (T₇: CPPU 10 ppm + Urea 1% at the pea stage, followed by N-ACTA 10 ppm + Brassinolides 4 ppm + Folic acid 40 ppm applied during July, August, and September). Based on the pooled data, Treatment T₇ surpassed all other treatments, recording the maximum number of fruits per plant (816.33), the highest fruit yield per plant (118.63 kg). Highest 'A' grade fruits (163.27), as well as 'B' and 'C' grade fruits was recorded in T₇.

Keywords: Nagpur mandarin, plant growth substances, *Citrus reticulata* blanco, fruit yield, economics

1. Introduction

In India, the Nagpur mandarin (*Citrus reticulata* Blanco) occupies a premier position among cultivated loose-skinned oranges, prominently grown in the Vidarbha region of Maharashtra (Anavrat, 2017; Shraddha *et al.*, 2024) [3]. Despite an estimated cultivation area of 1.2 to 1.4 lakh hectares in Vidarbha, the average productivity remains relatively low at 8 to 10 tonnes per hectare, which is significantly below the crop's genetic and regional potential. Maximizing the yield efficiency of mature orchards is a highly complex horticultural challenge. The transition from flowering and initial fruit set to final yield is heavily dictated by physiological factors, endogenous hormonal balances, environmental stressors, and the efficient mobilization of nutrients toward developing reproductive sinks. Under natural conditions, disturbances in the balance of endogenous growth regulators lead to reproductive losses, severely capping the final harvestable yield.

To maximize yield, the exogenous application of plant growth regulators (PGRs) and phytohormones has become an important component of modern agrotechnical practices (Monselise, 1979; Almeida *et al.*, 2004) [2, 15]. Historically, compounds such as auxins (NAA, 2,4-D) and gibberellins (GA3) have been extensively utilized in the global citrus industry to improve fruit set and enhance overall production efficiency (Anthony *et al.*, 1999; Nawaz *et al.*, 2008) [5, 16].

In recent years, new-generation growth promoters like CPPU, N-ACTA, Brassinolides, and Folic Acid have demonstrated exceptional efficacy in managing plant stress, enhancing cellular division, and optimizing the source-sink relationship. CPPU functions synergistically with endogenous auxins to profoundly enhance early cell division, plant growth, and sink strength in developing fruitlets (Zhang & Whiting, 2011; Xin Xie *et al.*, 2024) [23, 25]. Brassinolides act as potent steroidal hormones that maintain plant metabolism and developmental processes under environmental stress conditions, effectively acting to optimize yields (Roy, 1973; Peng *et al.*, 2004) [17, 19]. N-ACTA has been proven to channelize assimilate translocation directly to developing reproductive organs (Hota *et al.*, 2017a) [10]. Furthermore, Folic acid (vitamin B9) aids in crucial nucleic acid synthesis and one-carbon metabolism necessary for vigorous early reproductive cell division (Hanson & Gregory, 2011; Abd El-Rahman *et al.*, 2018) [1, 9].

2. Materials and Methods

2.1 Experimental site and weather conditions

The field experiment was conducted during year 2021 to 2023 at the experimental farm of the All India Coordinated Research Project on Fruits (Citrus), Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra. The site lies at 20°42' N latitude and 77°02' E longitude, with an elevation of 307.42 m above mean sea level (MSL). The experimental trial was executed on uniform, eighteen-year-old Nagpur mandarin trees that were planted at a standard spacing of 6 m × 6 m. The orchard soil consisted of medium to heavy black cotton soil, which was moderately deep, porous and possessed good drainage capabilities.

2.2 Experimental design and treatment details

The field trial was laid out using a Randomized Block Design (RBD) with 10 different treatments. These treatments were replicated three times, with two uniform trees forming a single experimental unit, resulting in 60 total trees under observation. The treatments comprised foliar applications of various growth regulators, applied initially at the pea-size stage of fruit development and subsequently at one-month intervals corresponding to July, August and September.

Treatment details

T ₁	NAA 10 PPM + Urea 1% (4 sprays).
T ₂	CPPU 10 PPM + Urea 1% (4 sprays).
T ₃	GA3 15 PPM + Urea 1% (4 sprays).
T ₄	2, 4-D 15 PPM + Urea 1% (4 sprays).
T ₅	N-ACTA 10 PPM + Brassinolides 4 PPM + Folic acid 40 PPM (4 sprays).
T ₆	NAA 10 PPM + Urea 1% (1 spray at pea size) followed by N-ACTA 10 PPM + Brassinolides 4 PPM + Folic acid 40 PPM (3 sprays in July, Aug, Sept).
T ₇	CPPU 10 PPM + Urea 1% (1 spray at pea size) followed by N-ACTA 10 PPM + Brassinolides 4 PPM + Folic acid 40 PPM (3 sprays in July, Aug, Sept).
T ₈	GA3 15 PPM + Urea 1% (1 spray at pea size) followed by N-ACTA 10 PPM + Brassinolides 4 PPM + Folic acid 40 PPM (3 sprays in July, Aug, Sept).
T ₉	2, 4-D 15 PPM + Urea 1% (1 spray at pea size) followed by N-ACTA 10 PPM + Brassinolides 4 PPM + Folic acid 40 PPM (3 sprays in July, Aug, Sept).
T ₁₀	Absolute control (No spray).

3. Results and Discussion

3.1 Effect on vegetative growth parameters

The pooled initial plant height across the orchard ranged from 4.14 m to 5.11 m, and the final height ranged from 4.41 m to 5.40 m. The highest was recorded in T₇ (5.03 m). These results align with the findings of Jyoti *et al.* (2024) in Nagpur mandarin, and Bagri *et al.* (2020) and Prem K. *et al.* (2020) [7, 18] in Kinnow mandarin, who also reported limited height variations post-PGR application.

The pooled data demonstrated that the significantly highest leaf area was recorded in T₇ (45.39 cm²), closely followed by T₈ (45.24 cm²) and T₆ (45.19 cm²), whereas the untreated control recorded the lowest (39.25 cm²). The sequential application of CPPU followed by N-ACTA and Brassinolides in T₇ actively stimulated cellular division and expansion, resulting in highest leaf area increase the overall photosynthetic capability of the canopy (Atheer M.I. Al Janabi *et al.*, 2017; Jyoti *et al.*, 2024) [6].

Table 1: Effect of different growth substances on Plant Height (m)

Treatments	Initial Plant Height (m)	Final Plant Height (m)	Increment (m)
T ₁	4.86	5.04	0.18
T ₂	4.78	5.02	0.24
T ₃	5.07	5.31	0.24
T ₄	4.14	4.41	0.27
T ₅	5.00	5.25	0.25
T ₆	5.11	5.40	0.29
T ₇	4.79	5.03	0.24
T ₈	4.48	4.71	0.23
T ₉	4.70	4.97	0.27
T ₁₀ (Control)	4.73	4.98	0.25
CD @ 5%	-	-	-

Table 2: Effect of different growth substances on Canopy Volume (m³)

Treatments	Canopy Volume (m ³)	Leaf area (cm ²)
T ₁	76.26	42.13
T ₂	78.60	43.32
T ₃	75.89	42.69
T ₄	76.98	42.44
T ₅	66.61	43.39
T ₆	74.98	45.19
T ₇	77.61	45.39
T ₈	74.47	45.24
T ₉	70.00	44.16
T ₁₀ (Control)	74.32	39.25
CD @ 5%	-	0.42

3.2 Effect on yield and yield-contributing characters

Based on the pooled data, Treatment T₇ recorded the highest total number of fruits per tree an average of 816.33 fruits, compared to 636.30 fruits in the untreated control. Correspondingly, T₇ recorded the significantly highest

pooled fruit yield per plant at 118.63 kg, outperforming the control at 76.35 kg. This is due to the combined effects of growth regulators and nutrients on the plant's reproductive physiology, confirming findings by Ansari *et al.* (2008), Jhade *et al.* (2020), and Sheikh *et al.* (2021)^[4].

Table 3: Effect of different growth substances on Yield and Efficiency

Treatments	Total Fruits per tree	Fruit Yield per plant (kg)	Yield Efficiency (kg/m ³)
T ₁	662.87	85.77	1.32
T ₂	712.74	97.67	1.46
T ₃	696.74	93.77	1.45
T ₄	684.60	90.28	1.38
T ₅	727.50	100.25	1.77
T ₆	775.14	111.04	1.74
T ₇	816.33	118.63	1.81
T ₈	781.04	112.56	1.78
T ₉	750.24	105.30	1.77
T ₁₀ (Control)	636.30	76.35	1.21
CD @ 5%	34.00	3.87	0.08

3.4 Graded fruit yield analysis: The fruits were graded by diameter into premium "A" Grade (>7.5 cm), "B" Grade (>6.5 cm), and "C" Grade (<6.5 cm). The maximum number of premium "A" grade fruits per plant was significantly achieved in T₇ (163.27), surpassing the control (127.26). T₇ also showed highest number of "B" grade fruits, an average of 367.35 compared to 286.34 in the control. Furthermore, T₇ recorded the highest "C" grade fruits (285.72) against the control (222.71).

Treatment T₇ has the highest number of fruits across all grades. The CPPU actively initiates widespread cellular division, while the subsequent applications of Brassinolides and N-ACTA provide the necessary metabolic support required for mass allocation without exhausting the tree (Uniyal *et al.*, 2015; Bharti *et al.*, 2016; Yaser *et al.*, 2016) [8, 22, 25].

Table 4: Effect of different growth substances on graded fruit yield

Treatments	"A" Grade Fruits (>7.5 cm)	"B" Grade Fruits (>6.5 cm)	"C" Grade Fruits (<6.5 cm)
T ₁	132.57	298.29	232.00
T ₂	142.55	320.73	249.46
T ₃	139.35	313.53	243.86
T ₄	136.92	308.07	239.61
T ₅	145.50	327.38	254.63
T ₆	155.03	348.81	271.30
T ₇	163.27	367.35	285.72
T ₈	156.21	351.47	273.36
T ₉	150.05	337.61	262.58
T ₁₀ (Control)	127.26	286.34	222.71
CD @ 5%	7.74	13.15	12.97

3.5 Leaf and soil nutrient status

Based on the pooled analysis, leaf Nitrogen ranged from 1.75% (T₁₀) to 2.20% (T₇), Phosphorus from 0.14% to 0.23%, and Potassium from 1.45% to 1.89%. While treatment T₇ showed higher leaf retention of all three elements, the analysis of variance confirmed that these differences were statistically non-significant.

Similarly, the final pooled status of soil available Nitrogen ranged from 205.04 to 213.01 kg/ha, available Phosphorus from 14.95 to 17.55 kg/ha, and available Potassium from 304.00 to 343.65 kg/ha. The available calcium carbonate in the soil also remained completely stable between 7.34% and 7.49%. these variations between treatments proved to be statistically non-significant.

Table 5: Effect of different growth substances on Leaf and Soil Nutrient Status

Treatments	Leaf N (%)	Leaf P (%)	Leaf K (%)	Soil N (kg/ha)	Soil P (kg/ha)	Soil K (kg/ha)	Soil CaCO ₃ (%)
T ₁	1.85	0.16	1.66	205.18	15.98	318.89	7.40
T ₂	2.00	0.17	1.72	207.63	16.53	309.10	7.42
T ₃	1.78	0.15	1.54	208.03	16.85	333.41	7.43
T ₄	1.82	0.15	1.65	208.64	16.38	323.05	7.36
T ₅	2.00	0.17	1.74	209.77	15.43	307.90	7.44
T ₆	2.18	0.21	1.84	206.95	15.10	304.28	7.41
T ₇	2.20	0.23	1.89	207.01	15.60	304.00	7.45
T ₈	2.08	0.20	1.80	211.37	14.95	305.90	7.47
T ₉	2.01	0.18	1.80	208.78	15.45	307.30	7.49
T ₁₀	1.75	0.14	1.45	205.24	17.00	342.11	7.34
CD @ 5%	NS	NS	NS	NS	NS	NS	NS

3.6 Economic viability

Treatment T₇ yielded the highest returns by a substantial margin, achieving a highly BCR of 5.89. Despite the supplementary capital costs associated with procuring and applying these advanced new-generation growth substances, the improvements observed in total yield and the shift toward premium marketable "A" and "B" grade fruits directly resulted into larger revenues.

Other treatments such as T₆ (5.67) and T₉ (5.62) also demonstrated high profitability. In contrast, the control group (T₁₀) recorded an economically inferior BCR of 2.46.

Table 6: Economics of treatment (Benefit Cost Ratio - Pooled Data)

Treatments	Benefit Cost Ratio (Pooled)
T ₁	3.54
T ₂	5.25
T ₃	4.30
T ₄	4.56
T ₅	4.50
T ₆	5.67
T ₇	5.89
T ₈	5.58
T ₉	5.62
T ₁₀ (Control)	2.46

4. Conclusion

Treatment T₇: a targeted sequential foliar spray of CPPU (10 ppm) + Urea (1%) at the pea-size stage, followed by monthly applications of N-ACTA (10 ppm) + Brassinolides (4 ppm) + Folic acid (40 ppm) from July through September. This specific chemical formulation optimized the plant's physiological source-sink dynamics, maximizing the total number of harvested fruits per plant (816.33), the highest fruit yield per plant (118.63 kg).

Treatment T₇ is economically viable benefit-cost ratio of 5.89. The application of CPPU, N-ACTA, Brassinolides, and Folic acid coordinates internal carbohydrate partitioning and provides a potent, to secure higher yields.

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