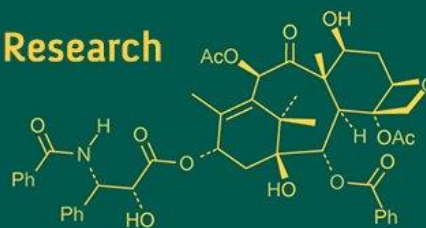


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Effect of growth retardants (Cycocel and Paclobutrazol) on flowering, yield and quality of Nagpur mandarin under heavy black cotton soil

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Abstract

The present investigation was carried out during 2025-26 at a cultivator's orchard in Shirajgaon Ardak, Tehsil Chandurbazar, District Amravati (Maharashtra), to evaluate the influence of two growth retardants- cycocel and paclobutrazol, on flowering, fruit yield and quality of Nagpur mandarin. Seven treatments- cycocel at 1000, 1500, 2000 ppm applied as foliar spray; paclobutrazol at 3, 6, 9 g a.i. per plant applied as soil drench and an untreated control - were laid out in a Randomized Block Design with three replications on 10-12 years old trees. Paclobutrazol at 9 g a.i. gave the earliest bud initiation and flowering, the quickest maturity, the greatest number of harvested fruits per plant. Among cycocel concentrations, 1500 ppm was the most consistent performer, recording the highest fruit set, fruit weight, juice content and highest yield. The untreated control lagged behind on nearly every parameter, including the lowest yield (38.78 kg plant⁻¹) and the highest fruit drop (36.11%). The results suggest that a restrained vegetative phase, brought about by either compound, redirects assimilate toward reproductive growth and improves both cropping efficiency and fruit quality, making paclobutrazol (9 g a.i. plant⁻¹, soil applied) and cycocel (1500 ppm, foliar applied) practical options for regulating Mrig bahar in Nagpur mandarin orchards on black cotton soils.

Keywords: Citrus reticulata, Nagpur mandarin, cycocel, paclobutrazol, growth retardant, flowering, fruit yield, fruit quality, Mrig bahar, black cotton soil

1. Introduction

Nagpur mandarin (*Citrus reticulata* Blanco) is one of the most economically important citrus cultivars of the Vidarbha region of Maharashtra, valued for its attractive appearance, pleasant taste and favourable market price (Morton, 1987) ^[15]. On heavy black cotton soils, however, the crop frequently suffers from excessive vegetative vigour, irregular flowering and inconsistent fruit yield, particularly under the Mrig bahar cropping cycle, in which flowering is triggered by moisture stress imposed during summer followed by the onset of the monsoon (Srivastava, Singh, & Huchche, 2000) ^[25].

Growth retardants have been investigated as tools for regulating vegetative growth and inducing more uniform flowering in citrus and other perennial fruit crops. Paclobutrazol [(2RS,3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1H-1,2,4-triazol-1-yl)pentan-3-ol] inhibits kaurene oxidase and thereby blocks gibberellin biosynthesis, reducing vegetative growth while promoting flower bud differentiation (Goldschmidt, Tamim, & Goren, 1998; Rademacher, 2000) ^[7, 17]. Chlormequat chloride (cycocel), which restricts gibberellic acid action and cell elongation, produces compact, sturdy growth without disturbing reproductive development (Fletcher, Gilley, Sankhla, & Davis, 2000) ^[6]. Both compounds have improved flowering synchronisation, fruit set, yield and quality in citrus and other fruit crops (Martínez-Fuentes *et al.*, 2013; Shirgure, Srivastava, & Singh, 2016; Jhade, Huchche, Pandey, & Verma, 2021) ^[10, 13, 24], yet research on their effect specifically in Nagpur mandarin grown on heavy black cotton soil remains scarce.

Considering these constraints, the present investigation was undertaken with the following objectives: (1) to study the effect of the application of growth retardants on flowering, fruiting and yield in Nagpur mandarin, and (2) to identify the most suitable growth retardant and concentration for improving flowering, fruiting and yield of Nagpur mandarin grown on heavy black cotton soil.

2. Materials and Methods

2.1 Experimental site and climate

The field experiment was conducted during 2025-2026 at a farmer's orchard in Shirajgaon Ardak, Tehsil Chandurbazar, District Amravati, Maharashtra, India (approximately 21.24° N, 77.75° E; elevation 300-350 m amsl), a region characterised by deep, moisture-retentive black cotton soils (Vertisols) suited to citrus, cotton and soybean. The climate is tropical and monsoonal, with summer maxima of 40-45 °C in May-June, monsoon rainfall of about 800-1000 mm from July to September, and a mild, dry winter (10-30 °C) from December to February that favours flowering, fruit set and quality development in Nagpur mandarin. Analytical work was carried out at the Analytical Laboratory,

Department of Fruit Science, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

2.2 Soil characteristics

Representative pre-experiment soil samples from the orchard were moderately alkaline (pH 8.10) and non-saline (EC 0.92 dS m⁻¹), with medium organic carbon (0.67%) and high available nitrogen (608 kg ha⁻¹), phosphorus (381 kg ha⁻¹), potassium (507 kg ha⁻¹) and sulphur (108 mg kg⁻¹). Copper (0.38 mg kg⁻¹), iron (5.36 mg kg⁻¹), zinc (0.69 mg kg⁻¹) and boron (0.32 mg kg⁻¹) were deficient or latently deficient, while manganese (14.20 mg kg⁻¹) was very high a pattern typical of alkaline Vertisols in citrus-growing tracts of Vidarbha (Brady & Weil, 2017) ^[1].

2.3 Experimental design and treatments

The trial was conducted on 10-12-year-old, uniform, bearing Nagpur mandarin trees planted at 6 × 6 m spacing, laid out in a Randomized Block Design (RBD) with seven treatments replicated thrice, three plants per replication (21 trees in total). Treatment details are given in Table 1.

Table 1: Treatment details

Treatment	Growth retardant	Concentration / dose	Application method
T1	Chlormequat chloride (Cycocel)	1000 ppm (2 ml/litre)	Foliar spray
T2	Chlormequat chloride (Cycocel)	1500 ppm (3 ml/litre)	Foliar spray
T3	Chlormequat chloride (Cycocel)	2000 ppm (4 ml/litre)	Foliar spray
T4	Paclobutrazol	3 g a.i. (12 ml/plant)	Soil (collar) drench
T5	Paclobutrazol	6 g a.i. (24 ml/plant)	Soil (collar) drench
T6	Paclobutrazol	9 g a.i. (36 ml/plant)	Soil (collar) drench
T7	Control	Natural stress (untreated)	

2.4 Application method

Paclobutrazol (25% w/v) was dissolved in water at the required dose and poured into a trench 60 cm from the tree trunk at 15 cm depth, then covered with soil, to ensure uptake through the root zone. Cycocel (50% SL) was diluted to the required concentration and applied as a foliar spray to the point of run-off using a knapsack sprayer, ensuring uniform canopy coverage. All plants received the same cultural practices throughout the study to ensure uniformity.

2.5 Observations recorded

Three tagged plants per treatment were observed for one cropping season (2025-2026). Plant height (m) and canopy volume [(mean of E-W and N-S spread)² × canopy height × 0.5236, m³] were recorded. Flowering parameters days to flower bud initiation, days to flower initiation were recorded on four tagged branches (E, W, N, S) per plant. Fruit physical characters (average fruit weight, equatorial and polar length, length: breadth ratio, fruit volume by water displacement, rind thickness, core diameter, number of segments and seeds) were measured on five representative fruits per treatment using an electronic balance and digital vernier calliper. Yield parameters recorded were days to fruiting, fruit set (%), days to maturity, fruit drop (%), number of fruits harvested per plant, and fruit yield (kg plant⁻¹ and t ha⁻¹). Physico-chemical quality was assessed for juice content (%), total soluble solids (digital refractometer, °Brix), titratable acidity (% citric acid, NaOH titration; Ranganna, 1986) ^[18], total and reducing sugars (Dubois phenol-sulphuric acid method; Sadasivam &

Manickam, 1996) ^[21], non-reducing sugars (by difference), TSS:acid ratio, and ascorbic acid (2,6-dichlorophenol indophenol titration; Mazumdar & Majumdar, 2003) ^[14].

2.6 Statistical analysis

Data were tabulated and analysed as a Randomized Block Design following Panse and Sukhatme (1976) ^[16] using OPSTAT. Where the F-test was significant, critical difference (C.D.) at the 5% level was computed for comparison of treatment means; non-significant differences are indicated as NS.

3. Results and Discussion

3.1 Plant growth parameters

Plant height and canopy volume varied significantly among treatments (Table 2). Paclobutrazol at 6 g a.i. produced the lowest plant height (3.36 m), whereas paclobutrazol at 9 g a.i. recorded the highest (3.86 m), against 3.78 m in the control; canopy volume followed a similar pattern, being lowest with paclobutrazol 3 g a.i. (4.18 m³) and highest with paclobutrazol 9 g a.i. (4.81 m³). Among cycocel concentrations, plant height and canopy volume tended to decline with increasing concentration. The restriction of vegetative growth under cycocel is consistent with its anti-gibberellin activity, which inhibits cell elongation and internodal length, producing a more compact canopy (Shirgure, Srivastava, & Singh, 2016) ^[24]; similar restriction of canopy development following paclobutrazol has been reported in Valencia orange (Delgado, Casamayor, Rodriguez, Cruz, & Fajardo, 1986) ^[5].

Table 2: Effect of cycocel and paclobutrazol concentration on plant growth parameters

Treatment	Plant height (m)	Canopy volume (m ³)
T1 - Cycocel (1000 ppm)	3.54	4.21
T2 - Cycocel (1500 ppm)	3.56	4.47
T3 - Cycocel (2000 ppm)	3.67	4.54
T4 - Paclobutrazol (3 g a.i.)	3.71	4.18
T5 - Paclobutrazol (6 g a.i.)	3.36	4.49
T6 - Paclobutrazol (9 g a.i.)	3.86	4.81
T7 - Control	3.78	4.51
F-test	Sig.	Sig.
SE(m)±	0.07	0.12
C.D. at 5%	0.22	0.37

3.2 Flowering parameters

Days to flower bud initiation and days to flower initiation differed significantly among treatments (Table 3). Paclobutrazol at 9 g a.i. induced the earliest bud initiation (47.00 days) and flower opening (53.67 days), while cycocel at 1500 ppm was the fastest among cycocel treatments (48.17 and 54.50 days, respectively); the untreated control was the slowest (57.50 and 62.83 days). Paclobutrazol is

known to up-regulate abscisic acid synthesis, mimicking water-stress signals that promote flower induction (Upreti *et al.*, 2013) ^[26], while the earlier bud initiation may also reflect suppressed vegetative growth and greater diversion of assimilates towards reproductive development, consistent with reports of increased flowering intensity in citrus following paclobutrazol application (Martínez-Fuentes *et al.*, 2013) ^[13].

Table 3: Effect of cycocel and paclobutrazol concentration on flowering parameters

Treatment	Days to flower bud initiation	Days to flower initiation
T1 - Cycocel (1000 ppm)	60.33	64.67
T2 - Cycocel (1500 ppm)	48.17	54.50
T3 - Cycocel (2000 ppm)	52.00	56.67
T4 - Paclobutrazol (3 g a.i.)	54.17	60.17
T5 - Paclobutrazol (6 g a.i.)	49.83	54.17
T6 - Paclobutrazol (9 g a.i.)	47.00	53.67
T7 - Control	57.50	62.83
F-test	Sig.	Sig.
SE(m)±	1.10	1.16
C.D. at 5%	3.43	3.46

3.3 Fruit physical characters

Average fruit weight and fruit volume were significantly affected by treatment (Table 4). Paclobutrazol at 3 g a.i. produced the heaviest (130.00 g) and largest (135.00 cm³) fruits overall, while cycocel at 1500 ppm was the best-performing cycocel treatment for both traits (122.33 g; 127.67 cm³); the control produced the smallest fruits (93.33 g; 104.33 cm³). Fruit length and breadth were not statistically significant, though cycocel (1500 ppm) and

paclobutrazol (9 g a.i.) numerically gave the greatest polar length (61.60 and 61.23 mm) and equatorial breadth (74.97 and 72.40 mm), both exceeding the control (57.40 mm). The increase in fruit weight and volume under growth-retardant treatment is consistent with enhanced translocation of photosynthates to developing fruit following suppression of vegetative sinks, as reported in lemon (Jain, Singh, & Misra, 2002) ^[9] and mandarin (Shirgure, Srivastava, & Huchche, 2014) ^[23].

Table 4: Effect of cycocel and paclobutrazol concentration on fruit physical characters (weight, length, breadth, volume)

Treatment	Fruit weight (g)	Length (mm)	Breadth (mm)	Fruit volume (cm ³)
T1 - Cycocel (1000 ppm)	111.00	59.97	67.20	115.00
T2 - Cycocel (1500 ppm)	122.33	61.60	74.97	127.67
T3 - Cycocel (2000 ppm)	107.33	58.53	67.90	110.00
T4 - Paclobutrazol (3 g a.i.)	130.00	60.57	71.50	135.00
T5 - Paclobutrazol (6 g a.i.)	109.67	59.70	68.30	112.33
T6 - Paclobutrazol (9 g a.i.)	122.00	61.23	72.40	126.67
T7 - Control	93.33	57.40	67.80	104.33
F-test	Sig.	NS	NS	Sig.
SE(m)±	2.99	3.85	3.19	2.72
C.D. at 5%	9.31			8.47

The number of fruit segments, rind thickness, core diameter, number of seeds and juice content did not differ significantly among treatments (Table 5), although paclobutrazol at 9 g a.i. numerically recorded the greatest number of segments (10.67) and core diameter (27.73 mm), and paclobutrazol at 3 g a.i. the highest juice content (54.93%), followed by cycocel 1500 ppm (51.26%). The relative stability of segment number across treatments

agrees with earlier reports that this trait is primarily genetically governed in Nagpur mandarin (Ingle, Rathod, & Shambharkar, 2001) ^[8] and citrus generally (Davies & Albrigo, 1994) ^[4]. The comparatively higher juice content under paclobutrazol and cycocel treatment likely reflects improved fruit development and greater accumulation of metabolites within the juice vesicles (Shirgure, Srivastava, & Singh, 2016) ^[24].

Table 5: Effect of cycocel and paclobutrazol concentration on fruit physical characters (segments, rind, core, seeds, juice content)

Treatment	No. of segments	Rind thickness (mm)	Core diameter (mm)	No. of seeds	Juice content (%)
T1 - Cycocel (1000 ppm)	9.00	4.00	24.50	9.33	48.03
T2 - Cycocel (1500 ppm)	9.67	5.10	26.83	11.67	51.26
T3 - Cycocel (2000 ppm)	9.00	4.37	25.90	10.00	44.31
T4 - Paclobutrazol (3 g a.i.)	9.67	3.30	26.83	10.00	54.93
T5 - Paclobutrazol (6 g a.i.)	9.33	2.70	26.20	12.67	50.09
T6 - Paclobutrazol (9 g a.i.)	10.67	3.57	27.73	10.00	52.58
T7 - Control	9.00	3.03	23.13	8.67	50.74
F-test	NS	NS	NS	NS	NS
SE(m)±	0.67	0.69	1.03	1.49	4.61
C.D. at 5%					

3.4 Fruit yield parameters

Days for fruiting, fruit set, days to maturity, fruit drop, number of fruits harvested and fruit yield were all significantly influenced by treatment (Tables 6 and 7). Paclobutrazol at 9 g a.i. required the fewest days for fruiting (59.67) and maturity (271.33), followed closely by cycocel 1500 ppm (60.83 and 273.00 days). The highest fruit set was recorded with cycocel 1500 ppm (56.15%), followed by paclobutrazol 9 g a.i. (54.28%). Similar acceleration of

flowering and harvest with paclobutrazol has been reported in mango (Burondkar *et al.*, 2013) [2] and with cycocel in Nagpur mandarin (Lal Singh, Kashyap, Khandwe, & Jatav, 2019-21). Fruit drop was lowest under cycocel 1000 ppm (27.08%) and highest in the control (36.11%), which may reflect a more favourable hormonal balance under growth-retardant treatment that limits abscission-layer formation at the fruit pedicel (Ranganna, Venkataramana, Mukundalakshmi, Swarajyalakshmi, & Sudhakar, 2017) [19].

Table 6: Effect of cycocel and paclobutrazol concentration on fruiting, fruit set, maturity and fruit drop

Treatment	Days for fruiting	Fruit set (%)	Days to maturity	Fruit drop (%)
T1 - Cycocel (1000 ppm)	72.00	49.26	281.33	27.08
T2 - Cycocel (1500 ppm)	60.83	56.15	273.00	32.84
T3 - Cycocel (2000 ppm)	64.33	50.39	290.33	31.42
T4 - Paclobutrazol (3 g a.i.)	65.50	53.91	278.00	28.62
T5 - Paclobutrazol (6 g a.i.)	61.50	49.27	276.00	32.61
T6 - Paclobutrazol (9 g a.i.)	59.67	54.28	271.33	30.13
T7 - Control	71.17	50.71	285.67	36.11
F-test	Sig.	Sig.	Sig.	Sig.
SE(m)±	1.29	1.17	2.61	0.81
C.D. at 5%	4.02	3.64	8.14	2.52

The number of fruits harvested per plant and fruit yield were maximum under paclobutrazol at 9 g a.i. (590.67 fruits; 71.96 kg plant⁻¹, 19.93 t ha⁻¹) and, for total yield, under paclobutrazol at 3 g a.i. (75.37 kg plant⁻¹; 20.87 t ha⁻¹), reflecting its combination of a moderately high fruit count with the heaviest individual fruits. Among cycocel treatments, 1500 ppm gave the best performance (563.67 fruits harvested; 69.05 kg plant⁻¹, 19.12 t ha⁻¹), while the

untreated control yielded least (416.00 fruits; 38.78 kg plant⁻¹, 10.74 t ha⁻¹). These increases corroborate the findings of Shurgure, Srivastava, and Singh (2016) [24] for Nagpur mandarin, who attributed such gains to effective imposition of moisture stress leading to profuse flowering and improved fruit retention, and are consistent with yield improvements reported for paclobutrazol in acid lime (Delgado *et al.*, 1986; Jain *et al.*, 2002) [5, 9].

Table 7: Effect of cycocel and paclobutrazol concentration on number of fruits and fruit yield

Treatment	No. of fruits/plant	Fruits harvested/plant	Fruit yield (kg/plant)	Fruit yield (t/ha)
T1 - Cycocel (1000 ppm)	629.67	511.33	56.81	15.73
T2 - Cycocel (1500 ppm)	739.33	563.67	69.05	19.12
T3 - Cycocel (2000 ppm)	711.67	538.00	57.70	15.98
T4 - Paclobutrazol (3 g a.i.)	725.67	580.00	75.37	20.87
T5 - Paclobutrazol (6 g a.i.)	680.00	523.33	57.56	15.87
T6 - Paclobutrazol (9 g a.i.)	721.67	590.67	71.96	19.93
T7 - Control	679.33	416.00	38.78	10.74
F-test	Sig.	Sig.	Sig.	Sig.
SE(m)±	13.89	29.19	3.91	1.09
C.D. at 5%	43.29	90.96	12.16	3.40

3.5 Fruit chemical (quality) characters

Total soluble solids (TSS) and titratable acidity varied significantly among treatments (Table 8). Paclobutrazol at 9 g a.i. recorded the highest TSS (10.73 °Brix), closely followed by cycocel 1500 ppm (10.63 °Brix), both markedly higher than the control (8.00 °Brix). Titratable acidity

peaked at 0.86% with paclobutrazol at 3 and 9 g a.i. The rise in TSS under growth-retardant treatment is consistent with greater accumulation of sugars and enhanced conversion of starch to soluble solids during ripening (Reddy, Shivu Prasad, & Upreti, 2013; Choudhary, Kumar, & Bakshi, 2024) [26].

Table 8: Effect of cycocel and paclobutrazol concentration on TSS and titratable acidity

Treatment	TSS (°Brix)	Titratable acidity (%)
T1 - Cycocel (1000 ppm)	8.83	0.77
T2 - Cycocel (1500 ppm)	10.63	0.84
T3 - Cycocel (2000 ppm)	8.50	0.77
T4 - Paclobutrazol (3 g a.i.)	10.07	0.86
T5 - Paclobutrazol (6 g a.i.)	9.50	0.76
T6 - Paclobutrazol (9 g a.i.)	10.73	0.86
T7 - Control	8.00	0.72
F-test	Sig.	Sig.
SE(m)±	0.59	0.02
C.D. at 5%	1.84	0.05

Reducing, non-reducing and total sugars all differed significantly among treatments (Table 9), with cycocel at 1500 ppm giving the highest values (4.67%, 3.24% and 7.92% respectively), followed by paclobutrazol at 9 g a.i. (4.41%, 3.11% and 7.52%); the control recorded the lowest

sugar levels throughout. The higher sugar accumulation under cycocel treatment may result from the diversion of carbohydrates from vegetative sinks towards developing fruit, in line with observations in grape (Kaur, Kaur, Kaur, & Arora, 2022) and mango (Sarker & Rahim, 2012).

Table 9: Effect of cycocel and paclobutrazol concentration on reducing, non-reducing and total sugars

Treatment	Reducing sugars (%)	Non-reducing sugars (%)	Total sugars (%)
T1 - Cycocel (1000 ppm)	3.69	2.77	6.47
T2 - Cycocel (1500 ppm)	4.67	3.24	7.92
T3 - Cycocel (2000 ppm)	3.47	2.63	6.11
T4 - Paclobutrazol (3 g a.i.)	4.14	3.00	7.15
T5 - Paclobutrazol (6 g a.i.)	3.91	2.87	6.78
T6 - Paclobutrazol (9 g a.i.)	4.41	3.11	7.52
T7 - Control	3.28	2.48	5.76
F-test	Sig.	Sig.	Sig.
SE(m)±	0.02	0.01	0.03
C.D. at 5%	0.07	0.03	0.10

The TSS:acid ratio was not significant, though cycocel 1500 ppm (12.65) and paclobutrazol 6 g a.i. (12.59) gave the numerically highest values (Table 10). Ascorbic acid content differed significantly, with paclobutrazol at 9 g a.i. recording the highest value (56.33 mg 100 ml⁻¹), followed by cycocel at 1500 ppm (52.08 mg 100 ml⁻¹); the control

was lowest (34.58 mg 100 ml⁻¹). The enhancement in ascorbic acid under paclobutrazol treatment supports the findings of Jain *et al.* (2002) [9] in lemon, who proposed that inhibition of gibberellin biosynthesis reduces the oxidative breakdown of ascorbic acid during fruit maturation.

Table 10: Effect of cycocel and paclobutrazol concentration on TSS:acid ratio and ascorbic acid content

Treatment	TSS:acid ratio	Ascorbic acid (mg/100 ml)
T1 - Cycocel (1000 ppm)	11.49	36.25
T2 - Cycocel (1500 ppm)	12.65	52.08
T3 - Cycocel (2000 ppm)	10.96	31.67
T4 - Paclobutrazol (3 g a.i.)	11.75	51.67
T5 - Paclobutrazol (6 g a.i.)	12.59	45.00
T6 - Paclobutrazol (9 g a.i.)	12.47	56.33
T7 - Control	11.18	34.58
F-test	NS	Sig.
SE(m)±	0.74	4.16
C.D. at 5%		12.95

4. Conclusion

The concentration of cycocel and paclobutrazol applied significantly influenced flowering, fruit set, fruit yield and the physico-chemical quality of Nagpur mandarin grown on heavy black cotton soil. Paclobutrazol at 9 g a.i. per plant performed best for days to flower bud initiation, days to flower initiation, days for fruiting, days to maturity, number of fruits harvested per plant, fruit yield, total soluble solids and ascorbic acid content. Cycocel at 1500 ppm performed best for fruit set, fruit weight, fruit length, fruit breadth, juice content, reducing sugars, non-reducing sugars, total sugars and TSS:acid ratio. Paclobutrazol (9 g a.i. plant⁻¹, soil-applied) and cycocel (1500 ppm, foliar-applied) may therefore be recommended as effective, complementary

treatments for regulating Mrig bahar flowering and improving the yield and quality of Nagpur mandarin under heavy black cotton soil conditions. As these conclusions are based on a single season of study, further multi-year trials are recommended to validate and refine the findings before wider extension recommendation.

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Competing Interests

Authors have declared that no competing interests exist.

Authors' Contributions

This work was carried out in collaboration among all authors. Author Mohod Manjiri Mangesh designed the study, conducted the field experiment and laboratory analyses, performed the statistical analysis, and wrote the first draft of the manuscript. Author U. A. Raut, as Chairman of the Advisory Committee, supervised the research and provided overall guidance on methodology and interpretation. Authors S. G. Bharad, S. V. Gholap and S. A. Bhuyar, as members of the Advisory Committee, provided guidance on experimental design and data interpretation and reviewed the manuscript. All authors read and approved the final manuscript.

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