Effect of ultra high-density planting, paclobutrazol and potassium nitrate on yield and quality of mango (*Mangifera indica* L) cv Kesar in western Maharashtra

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ABSTRACT

Mango (*Mangifera indica* L) cv Kesar is a commercially important cultivar valued for its superior fruit quality and market demand. The present investigations were conducted during 2020-21 to 2022-23 at Rahuri and Ganeshkhind, Pune (Maharashtra) to evaluate the effect of ultra high-density planting (UHDP), paclobutrazol (PBZ) and potassium nitrate (KNO_3) on growth, yield, fruit quality and economic returns. The experiment was laid out in a factorial randomized block design with four planting densities, three PBZ doses and three KNO_3 concentrations. Results indicated that planting density significantly influenced vegetative growth and yield parameters. Wider spacing promoted greater canopy development, while closer spacing (3 m × 2 m) resulted in the highest yield per hectare (14.69 tonnes/ha) due to increased plant population. Paclobutrazol effectively regulated vegetative growth and enhanced flowering and yield, with higher doses reducing plant vigour. Potassium nitrate showed limited effect on vegetative growth but improved fruit set and yield marginally. Fruit quality parameters such as TSS, acidity and TSS-acidity ratio showed only slight variation among treatments, indicating stability of fruit quality across different management practices. Pest and disease incidence was slightly lower under wider spacing due to better air circulation. Economic analysis revealed that treatment $D_1P_1K_2$ was the most profitable, recording the highest yield (15.12 tonnes/ha), net return (Rs 323,826.09) and B-C ratio (3.50). Overall, the study demonstrated that UHDP combined with optimum PBZ and KNO*f* application e nhances productivity and profitability of mango cv Kesar under western Maharashtra conditions.

Keywords: Mango cv Kesar; Ultra high-density planting; Paclobutrazol; Potassium nitrate; Yield; Fruit quality

INTRODUCTION

Mango (*Mangifera indica* L) is one of the most important tropical fruit crops, valued worldwide for its excellent flavour, nutritional quality and economic importance. India is the largest producer with 22.4 million metric tons, which contributes about 45 per cent of total world's total production (Tony et al 2025).

Among the commercial cultivars, cv Kesar is highly preferred for its attractive saffron-coloured pulp, pleasant aroma and superior processing quality. Mango's low output is due to inadequate orchard floor management, sparse planting density, poor canopy control and lack of training, pruning, nutrient and water management practices (Srivastava et al 2021).

In recent years, high-density and ultra high density planting (UHDP) systems have emerged as effective approaches for increasing productivity per unit area. UHDP in mango is an efficient, modern technique that optimizes resource use to substantially increase yield, profitability and uniform export-quality fruit production compared to conventional methods (Singh et al 2017). However, maintaining optimum vegetative growth and canopy architecture under such intensive planting systems remains a major challenge, as excessive vegetative growth often reduces light penetration and adversely affects flowering and fruit set.

Plant growth regulators and flowering inducers are widely used to manage tree vigour and enhance

flowering in mango orchards. Paclobutrazol (PBZ), a triazole-based growth retardant, suppresses vegetative growth by inhibiting gibberellin biosynthesis and promotes flowering, fruit set and yield in mango (Reddy and Kurian 2008, Yeshitela et al 2004). Similarly, potassium nitrate (KNO_3) has been widely used as a foliar spray to induce flowering by breaking bud dormancy and stimulating reproductive growth, particularly in regions with irregular flowering (Davenport 2007). The combined application of paclobutrazol and potassium nitrate has also been reported to improve flowering behaviour and yield attributes in mango under different planting systems (Swain et al 2023).

Western Maharashtra is an important mango-growing region suitable for cultivation of cv Kesar. However, limited information is available regarding the combined effect of UHDP, paclobutrazol and potassium nitrate on yield and fruit quality of mango under this region. Therefore, the present investigations were conducted to evaluate the effect of UHDP, paclobutrazol and potassium nitrate on yield and quality of mango cv Kesar under the agro-climatic conditions of western Maharashtra.

MATERIAL and METHODS

The experiment was conducted during three consecutive seasons (2020-21 to 2022-23) on the research farm at Rahuri and Ganeshkhind, Pune, Maharashtra. The soil at both locations was well-drained, medium black and suitable for mango cultivation. The experiment was laid out in a factorial randomized block design with three replications. The treatments included planting densities (D_1: 3 m × 2 m, D_2: 3 m × 3 m, D_3: 4 m × 2 m and D_4: 4 m × 3 m); paclobutrazole doses (P_1: 0.5 g ai/tree, P_2: 1.0 g ai/tree and P_3: 1.5 g ai/tree) and KNO_3 concentrations (K_1: 1%, K_2: 2% and K_3: 4%).

Healthy grafts of mango cv Kesar were planted during June 2017. The plants were pruned properly during initial stage to develop proper framework and every year light or medium pruning was done as and when required after harvesting of fruits for canopy management. Paclobutrazol was applied as soil drench during September, while KNO_3 was applied as foliar spray at the pre-flowering stage. Standard cultural practices were followed uniformly. Observations were recorded on fruit length, fruit breadth, fruit weight, number of fruits per plant, yield per hectare, total soluble solids (TSS), acidity and TSS-acidity ratio. Data were analyzed statistically as suggested by Panse and Sukhatme (1967) and pooled means over three years were computed.

RESULTS and DISCUSSION

Effect of planting density, paclobutrazol and KNO_3 on plant growth characters: The data presented in Table 1 clearly indicate that planting density significantly influenced vegetative growth parameters of mango cv Kesar. Among the treatments, D_2 (3 m × 3 m), D_3 (4 m × 2 m) and D_4 (4 m × 3 m) recorded the highest plant spread (E-W) with mean of 1.71, 1.63 and 1.60 m respectively, which were at par and the lowest spread (1.55 m) was observed in D_1 (3 m × 2 m), though it was at par with D_4 (1.60 m) and D_3 (1.63 m). Similarly, the maximum plant spread (N-S) was recorded under D_2 (1.852 m) and D_4 (1.760 m), which were at par, while D_3 (1.433 m) and D_1 (1.507 m) recorded the minimum, the two being at par. Plant height was highest under D_2 (2.012 m) and D_4 (1.927 m), which were at par and lowest under D_3 (1.723 m) and D_1 (1.835 m), which were at par. These results indicate that moderate spacing favours better canopy development compared to closer spacing due to reduced competition for light, nutrients and space, which is in agreement with earlier findings in mango under high-density planting systems (Singh et al 2010, Solanki et al 2021). Paclobutrazol application significantly affected vegetative growth. The lowest dose P_1 (0.5 g ai) recorded the highest (1.66 m) followed by P_2 (1.0 g ai) (1.62 m) and P_3 (1.5 g ai) the lowest (1.58 m) plant spread (E-W). P_1 (1.672 m) and P_2 (1.643 m) resulted in higher plant spread (N-S), which were at par as compared to 1.597 m in P_3. P_1 (1.957 m) and P_2 (1.860 m) were at par for higher plant height compared to 1.812 m in P_3, though P_3 was at par with P_2. The reduction in growth with higher paclobutrazol levels may be attributed to inhibition of gibberellin biosynthesis, which suppresses shoot elongation and canopy expansion, resulting in compact tree growth (Burondkar and Gunjate 1993, Singh and Ranganath 2006, Solanki et al 2021). The affect of potassium nitrate levels on growth parameters was non-significant. Potassium nitrate mainly improves physiological activities and is more associated with flowering induction rather than vegetative growth in mango (Sarker and Rahim 2013). The interaction effects of planting density, paclobutrazole and KNO_3 were significant for a few growth parameters but the variation was narrow. The D × P and D × K interactions

Table 1. Effect of planting density, paclobutrazole and KNO_3 on growth parameters of mango cv Kesar (pooled data for 2020-21 to S2022-23)

Treatment	Plant spread (E-W)			Plant spread (N-S)			Plant height (m)		
	Rahuri	Pune	Mean	Rahuri	Pune	Mean	Rahuri	Pune	Mean
Planting density (m)									
D_1 (3 × 2)	1.98	1.12	1.55	1.82	1.190	1.507	2.38	1.287	1.835
D_2 (3 × 3)	2.31	1.11	1.71	2.51	1.190	1.852	2.70	1.320	2.012
D_3 (4 × 2)	2.14	1.12	1.63	1.68	1.187	1.433	2.13	1.320	1.723
D_4 (4 × 3)	2.14	1.05	1.60	2.37	1.153	1.760	2.54	1.313	1.927
SEm(±)	0.04	0.01	0.02	0.03	0.03	0.01	0.09	0.02	0.03
$CD_{0.05}$	0.10	0.04	0.13	0.09	NS	0.10	NS	NS	0.17
Paclobutrazole (g ai)									
P_1 (0.5)	2.25	1.08	1.66	2.17	1.180	1.672	2.61	1.303	1.957
P_2 (1.0)	2.15	1.09	1.62	2.11	1.173	1.643	2.40	1.313	1.860
P_3 (1.5)	2.03	1.13	1.58	2.01	1.183	1.597	2.30	1.320	1.812
SEm(±)	0.03	0.11	0.01	0.03	0.03	0.01	0.08	0.02	0.02
$CD_{0.05}$	0.09	0.03	0.03	0.08	NS	0.03	0.22	NS	0.14
KNO_3 (%)									
K_1 (1)	2.16	1.12	1.64	2.11	1.180	1.643	2.41	1.303	1.858
K_2 (2)	2.15	1.09	1.62	2.10	1.183	1.643	2.47	1.313	1.890
K_3 (4)	2.12	1.09	1.61	2.08	1.170	1.625	2.43	1.310	1.870
SEm(±)	0.03	0.01	0.01	0.03	0.03	0.01	0.08	0.02	0.01
$CD_{0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS
Density × Paclobutrazole (D × P)									
SEm(±)	0.06	0.02	0.04	0.06	0.05	0.03	0.16	0.03	0.07
$CD_{0.05}$	NS	0.06	0.12	NS	NS	0.08	NS	0.10	0.23
Density × KNO_3 (D × K)									
SEm(±)	0.06	0.02	0.04	0.06	0.08	0.03	0.16	0.03	0.07
$CD_{0.05}$	NS	0.06	0.12	NS	NS	0.08	NS	NS	0.22
Paclobutrazole × KNO_3 (P × K)									
SEm(±)	0.06	0.02	0.02	0.05	0.07	0.01	0.14	0.03	0.04
$CD_{0.05}$	NS	0.06	0.07	NS	NS	0.03	NS	NS	0.17
Density × Paclobutrazole × KNO_3 (D × P × K)									
SEm(±)	0.11	0.04	0.04	0.10	0.06	0.03	0.28	0.10	0.21
$CD_{0.05}$	NS	0.11	0.16	NS	NS	0.09	NS	NS	0.61
Treatments	2.82	-	2.82	2.40	-	2.40	3.12	-	3.12
Control	2.14		2.14	2.10	-	2.10	2.44	-	2.44
SEm(±)	0.06	-	0.06	0.05	-	0.05	0.15	-	0.15
$CD_{0.05}$	0.14	-	0.14	0.16	-	0.16	0.41	-	0.41

NS = Non-significant

showed significant differences in plant spread and height, with values ranging from 1.55-1.71 m (E-W spread), 1.433-1.852 m (N-S spread) and 1.723-2.012 m (plant height), indicating only slight improvement under better treatment combinations. Similarly, the P × K interaction showed moderate variation with values of 1.58-1.66 m (E-W spread), 1.597-1.672 m (N-S spread) and 1.812-1.957 m (plant height). The three-way interaction (D × P × K) had minimal effect, as most treatments remained at par. Overall, interaction effects were significant but small in magnitude, suggesting a limited influence on growth compared to main effects. As a whole, treated plants recorded higher plant spread (E-W) (2.82 m), plant spread (N-S) (2.40 m) and plant height 3.12 m, whereas, control plants recorded lower plant spread (E-W) (2.14 m), plant spread (N-S) (2.10 m) and plant height (2.44 m). This reduction in vegetative growth in treated plants suggests that the use of growth regulators helps maintain manageable canopy size in high-density mango orchards, which supports findings reported in recent studies on mango production systems (Solanki et al 2021, Singh et al 2010).

Effect of planting density, paclobutrazol and KNO_3 on yield attributes: The data in Table 2 exhibit that there was no effect of planting density on fruit length. D_4 recorded more number of fruits per plant (46.76) at par with D_2 (42.55) and D_3 (42.31) in comparison to lower number (39.53) in D_1, which on the other hand, was at par with D_2 and D_3. P_1 resulted in higher fruit length (11.38 cm) compared to 11.16 cm in P_2 and 11.09 cm in P_3, the latter two being at par. However, there was no affect of paclobutrazole on fruit breadth and number of fruits per plant. KNO_3 did not affect the fruit length and breadth. At the same time, K_2 (2%) and K_1 (1%) lead to higher number of fruits per plant (43.33 and 43.01 respectively) compared to 42.02 in K_3 (4%). The D × P interaction showed significant differences mainly in fruit breadth and number of fruits per plant. The number of fruits per plant varied from about 39.53 to 46.76, indicating relatively higher yield under favourable combinations, while fruit breadth showed only slight variation (6.37-6.54 cm). Similarly, the D × K interaction influenced fruits per plant, with values ranging from 39.53 to 46.76, suggesting better performance under suitable combinations, whereas, fruit size parameters remained nearly stable. The P × K interaction also showed moderate variation, particularly in fruits per plant (41.93-43.70), while fruit length (11.09-11.38 cm) and breadth (6.43-6.50 cm) exhibited minimal differences.

The three-way interaction (D × P × K) had limited effect, with most treatments remaining at par and only slight variation observed in fruits per plant. Overall, interaction effects were significant but small, indicating that yield parameters were influenced more by individual factors than their combined interactions. Wider spacing likely reduced competition among plants and improved canopy development and fruiting (Singh et al 2010, Solanki et al 2021). However, fruit weight remained relatively similar across treatments with only slight variations, indicating that planting density had minimal influence on individual fruit size. Paclobutrazol treatments showed minor variation in fruit size parameters. Paclobutrazol enhances reproductive growth by suppressing vegetative growth and promoting flowering (Burondkar and Gunjate 1993, Yeshitela et al 2004). Potassium nitrate application improves physiological activity and enhances flowering (Sarker and Rahim 2013). While comparing the affect of treatments with that of control, it was observed that fruit length and breadth remained unaffected due to treatments. However, number of fruits per plant was higher (42.94) due to treatments as compare to control (31.67).

Effect of planting density, paclobutrazol and KNO_3 on fruit weight and yield: Data in Table 3 show that D_4 (229.65 g), D_3 (228.88 g) and D_2 (227.72 g) gave higher fruit weight as compared to D_1 (226.64 g). However, D_1 was at par with D_2. D_4 (10.72 kg), D_2 (9.53 kg) and D_3 (9.50 kg) were also at par for higher yield per plant in comparison to D_1 (8.82 kg), though D_1 was also at par with D_3 and D_2. While calculating the yield per hectare, D_1 resulted in highest yield (14.69 tonnes) as compared to 8.93 and 10.59 tonnes per hectare in D_4 and D_2 respectively, the latter two treatments being at par. Paclobutrazole treatment did influence fruit weight and fruit yield per plant. Its treatment P_3 and P_2 lead to higher yield per hectare (11.81 and 11.49 tonnes), the two being at par, compared to 11.28 tonnes in P_1, which was at par with P_2. Like paclobutrazole, KNO_3 also did not affect the fruit weight and fruit yield per plant. K_1 and K_2 resulted in 11.63 tonnes per hectare yield each higher than K_3 (11.33 tonnes). The D × P interaction showed significant differences mainly in fruit weight and yield. Fruit weight varied within a close range of about 226.64-229.65 g, indicating only slight variation among combinations, whereas, yield per plant ranged from 8.82 to 10.72 kg and yield per hectare from 8.93 to 14.69 tonnes, suggesting comparatively better performance under favourable combinations. Similarly, the D × K

Table 2. Effect of planting density, paclobutrazole and KNO_3 on fruit parameters of mango cv Kesar (pooled data for 2020-21 to S2022-23)

Treatment	Fruit length (cm)			Fruit breadth (cm)			Fruits/plant		
	Rahuri	Pune	Mean	Rahuri	Pune	Mean	Rahuri	Pune	Mean
Planting density (m)									
D_1 (3 × 2)	11.68	10.80	11.24	6.54	6.19	6.37	34.47	44.59	39.53
D_2 (3 × 3)	11.27	11.10	11.18	6.49	6.41	6.45	43.58	41.52	42.55
D_3 (4 × 2)	11.23	11.18	11.20	6.51	6.54	6.53	42.79	41.84	42.31
D_4 (4 × 3)	11.23	11.20	11.21	6.51	6.58	6.54	50.92	42.59	46.76
SEm(±)	0.27	0.11	0.08	0.03	0.07	0.05	1.43	1.34	0.30
$CD_{0.05}$	NS	0.38	NS	NS	0.26	0.15	2.23	4.63	4.77
Paclobutrazole (g ai)									
P_1(0.5)	11.61	11.14	11.38	6.51	6.49	6.50	40.00	43.85	41.93
P_2(1.0)	11.24	11.09	11.16	6.51	6.34	6.43	44.71	40.75	42.73
P_3(1.5)	11.21	10.98	11.09	6.51	6.44	6.48	44.10	43.30	43.70
SEm(±)	0.24	0.07	0.06	0.03	0.06	0.01	0.45	1.78	0.60
$CD_{0.05}$	NS	0.27	0.18	NS	0.25	0.03	1.24	7.00	NS
KNO_3(%)									
K_1(1)	11.25	11.09	11.17	6.52	6.57	6.55	43.51	42.52	43.01
K_2(2)	11.56	11.07	11.32	6.52	6.59	6.56	43.34	43.32	43.33
K_3(4)	11.24	11.06	11.15	6.50	6.55	6.53	41.96	42.07	42.02
SEm(±)	0.24	0.02	0.05	0.03	0.02	0.03	0.45	0.17	0.26
$CD_{0.05}$	NS	0.04	NS	NS	0.05	NS	1.24	0.33	0.79
Density × Paclobutrazole (D × P)									
SEm(±)	0.48	0.18	0.23	0.06	0.12	0.07	0.89	3.68	2.27
$CD_{0.05}$	NS	0.51	0.77	NS	0.36	0.23	2.48	9.89	7.48
Density × KNO_3 (D × K)									
SEm(±)	0.48	0.11	0.21	0.06	0.08	0.08	0.89	1.34	1.29
$CD_{0.05}$	NS	0.32	NS	NS	0.25	NS	NS	3.92	4.26
Paclobutrazole × KNO_3 (P × K)									
SEm(±)	0.41	0.04	0.21	0.05	0.04	0.04	0.77	1.61	0.94
$CD_{0.05}$	NS	0.07	NS	NS	0.08	0.12	NS	4.82	3.65
Density × Paclobutrazole × KNO_3 (D × P × K)									
SEm(±)	0.82	0.19	0.64	0.10	0.15	0.14	1.55	3.41	4.03
$CD_{0.05}$	NS	0.54	1.19	NS	0.41	0.27	NS	9.59	7.44
Treatments	11.35	-	11.35	6.55	-	6.55	42.94	-	42.94
Control	11.32	-	11.32	6.51	-	6.51	31.67	-	31.67
SEm(±)	0.43	-	0.43	0.05	-	0.05	0.82	-	0.82
$CD_{0.05}$	NS	-	NS	NS	-	NS	2.27	-	2.27

NS = Non-significant

Table 3. Effect of planting density, paclobutrazole and KNO_3 on fruit weight and yield parameters of mango cv Kesar (pooled data for 2020-21 to S2022-23)

Treatment	Fruit weight (g)			Yield/plant (kg)			Yield/ha (tonnes)		
	Rahuri	Pune	Mean	Rahuri	Pune	Mean	Rahuri	Pune	Mean
Planting density (m)									
D_1 (3 x 2)	234.39	221.04	226.64	8.11	9.53	8.82	13.51	15.87	14.69
D_2 (3 x 3)	232.71	220.58	227.72	10.26	8.80	9.53	11.39	9.78	10.59
D_3 (4 x 2)	238.90	218.85	228.88	10.18	8.81	9.50	12.72	11.06	11.89
D_4 (4 x 3)	232.95	226.35	229.65	12.18	9.26	10.72	10.14	7.71	8.93x
SEm(±)	0.85	0.84	0.80	0.12	0.39	0.22	0.13	0.72	0.26
$CD_{0.05}$	2.37	2.34	2.20	0.34	1.36	1.39	0.37	2.49	1.66
Paclobutrazole (g ai)									
P_1 (0.5)	238.10	221.99	230.05	9.55	9.39	9.47	11.17	11.38	11.28
P_2 (1.0)	234.75	218.34	226.55	10.60	8.64	9.62	12.47	10.51	11.49
P_3 (1.5)	231.36	224.78	228.07	10.39	9.26	9.83	12.19	11.43	11.81
SEm(±)	0.74	4.04	4.57	0.11	0.41	0.13	0.12	0.48	0.15
$CD_{0.05}$	2.05	15.89	NS	0.30	1.60	NS	0.32	1.89	0.45
KNO_3 (%)									
K_1 (1)	237.79	223.10	230.44	10.37	9.18	9.77	12.20	11.05	11.63
K_2 (2)	232.33	220.78	226.56	10.41	9.18	9.80	11.98	11.28	11.63
K_3 (4)	234.08	221.24	227.66	10.20	8.94	9.57	11.66	10.99	11.33
SEm(±)	0.74	0.98	1.56	0.30	0.06	0.22	0.12	0.09	0.06
$CD_{0.05}$	2.05	1.94	NS	0.39	0.12	NS	0.32	0.18	0.18
Density × Paclobutrazole (D × P)									
SEm(±)	1.47	6.80	7.77	0.21	0.65	0.45	0.23	0.87	0.55
$CD_{0.05}$	4.10	NS	NS	0.59	1.91	1.47	0.64	2.55	1.81
Density × KNO_3 (D × K)									
SEm(±)	1.47	4.33	3.11	0.21	0.38	0.36	0.23	0.67	0.43
$CD_{0.05}$	4.10	12.67	NS	NS	1.12	1.19	NS	1.97	1.42
Paclobutrazole × KNO_3 (P × K)									
SEm(±)	1.28	4.21	2.24	0.18	0.37	0.21	0.20	0.44	0.26
$CD_{0.05}$	3.55	12.62	NS	NS	1.11	0.82	NS	1.31	NS
Density × Paclobutrazole × KNO_3 (D × P × K)									
SEm(±)	2.55	7.78	8.80	0.37	0.69	0.87	0.40	0.90	0.99
$CD_{0.05}$	NS	21.67	NS	NS	1.93	1.61	NS	2.55	1.83
Treatment	234.74	-	234.74	10.18	-	10.18	11.94	-	11.94
Control	231.34	-	231.34	7.45	-	7.45	8.01	-	8.01
SEm(±)	1.34	-	1.34	0.19	-	0.19	0.21	-	0.21
$CD_{0.05}$	3.14	-	3.14	0.54	-	0.54	0.59	-	0.59

NS = Non-significant

interaction influenced yield parameters, with yield per plant varying from 8.82 to 10.72 kg and yield per hectare from 8.93 to 14.69 tonnes, while fruit weight remained nearly stable (226.64-229.65 g). The P × K interaction also showed moderate variation in yield per plant (9.47-9.83 kg) and yield per hectare (11.28-11.81 tonnes), whereas, fruit weight exhibited minimal differences (226.55-230.05 g). The three-way interaction (D × P × K) had limited effect, with most treatment combinations remaining at par and only slight variation observed in yield parameters. Overall, the interaction effects were significant but small, indicating that yield was influenced more by individual factors than by their combined interactions.

This clearly demonstrates that yield per unit area increases with increasing plant population despite relatively lower yield per plant. Similar findings have been reported by Singh et al (2010), Solanki et al (2021) and Swain et al (2025) who observed that high density planting systems significantly enhance productivity in mango orchards. Increased yield with higher paclobutrazol levels may be due to suppression of vegetative growth and improved flowering and fruit set (Burondkar and Gunjate 1993, Yeshitela et al 2004). The improvement in yield due to potassium nitrate may be attributed to enhanced physiological activity and better fruit set (Sarker and Rahim 2013). Treated plants recorded significantly higher fruit weight (234.74 g), yield per plant (10.18 kg) and yield per hectare (11.94 tonnes) compared to 231.34 g fruit weight, 7.45 kg yield per plant and 8.01 tonnes per hectare yield indicating that growth regulator and nutrient treatments improved productivity of mango cv Kesar.

Effect of planting density, paclobutrazol and KNO_3 on fruit quality parameters: The data in Table 4 exhibit that the higher TSS of 16.17 and 16.06 °B was recorded under D_3 and D_4 respectively, which were at par and lower in and D_1 (15.73 °B) and D_2 (15.88 °B), the two treatments also being at par. Higher fruit acidity was observed in D_1 (0.283%), D_2 (0.279%) and D_3 (0.276%), the treatment being at par, than D_4 (0.271%), which on the other hand, was at par with D_3 and D_4. Higher TSS-acidity ratio of 58.76 and 58.05 was recorded in D_4 and D_2 respectively, the two being at par. Lower TSS-acidity ratio was recorded in D_1 (56.97) and D_3 (56.98), the two being at par. The D × P interaction showed slight variation in TSS and acidity. TSS values ranged around 15.73-16.17 °B, while acidity varied marginally from 0.271-0.283 per cent, indicating minimal influence of combined treatments on these parameters. Similarly, the D × K interaction exhibited small differences, with TSS ranging from 15.73-16.17 °B and acidity from 0.271-0.283 per cent, suggesting that most treatment combinations remained comparable. The P × K interaction also showed very narrow variation, where TSS varied between 15.92-16.01 °B and acidity remained almost stable around 0.277-0.282 per cent. The three-way interaction (D × P × K) had limited effect, as most combinations were at par. The TSS-acidity ratio varied slightly within the range of 56.97-58.76, indicating only marginal improvement under certain combinations. Overall, interaction effects were negligible, suggesting that quality parameters were largely stable and influenced more by individual factors than their combined interactions.

The results indicated slightly better fruit quality under wider spacing due to improved light interception and nutrient availability (Singh et al 2010, Solanki et al 2021). Paclobutrazol did affect the quality which may be attributed to improved carbohydrate accumulation and better assimilate partitioning towards fruits (Burondkar and Gunjate 1993, Yeshitela et al 2004). Potassium nitrate also had effect on fruit quality. This may be due to the role of potassium in sugar translocation and fruit maturation (Sarker and Rahim 2013). The treatments had no affect on fruit TSS and acidity when compared with control. However, TSS-acidity ratio was higher (59.15) in treatments as compared to 56.81 in control. Similar findings have been reported by Davenport (2007), who indicated that paclobutrazol primarily affects flowering physiology rather than fruit quality characteristics.

Effect of planting density, paclobutrazol and KNO_3 on pest and disease incidence: Table 5 indicate that planting density had significant effect on pests and diseases in mango cv Kesar. Stem borer incidence was highest (14.54%) under D_1 followed by D_2 (11.84%) and the lowest under D_4 (9.18%) and D_3 (9.59%), the latter two being at par. Powdery mildew index was observed highest in D_1 (18.80%) and lowest in D_4 (13.98%), the latter, on the other hand being at par with D_3 (16.36%). There was no effect of paclobutrazol or KNO_3 on pest or disease incidence. The D × P interaction showed minor variation in stem borer incidence (9.18-14.54%) and powdery mildew (13.98-18.80%), indicating only a small influence of combined treatments. Similarly, the D × K interaction exhibited limited differences, where stem borer incidence ranged from 9.18-14.54 per cent and powdery mildew from

Table 4. Effect of planting density, paclobutrazole and KNO_3 on fruit quality parameters of mango cv Kesar (pooled data for 2020-21 to S2022-23)

Treatment	TSS (^{O}B)			Acidity (%)			TSS-acidity ratio		
	Rahuri	Pune	Mean	Rahuri	Pune	Mean	Rahuri	Pune	Mean
Planting density (m)									
D_1 (3 x 2)	16.50	14.96	15.73	0.283	0.283	0.283	59.98	53.97	56.97
D_2 (3 x 3)	16.48	15.28	15.88	0.277	0.281	0.279	57.43	58.66	58.05
D_3 (4 x 2)	16.50	15.83	16.17	0.280	0.272	0.276	59.57	54.39	56.98
D_4 (4 x 3)	16.48	15.63	16.06	0.28	0.262	0.271	59.61	57.91	58.76
SEm(±)	0.03	0.24	0.08	0.003	0.012	0.003	0.59	2.75	0.30
$CD_{0.05}$	NS	0.84	0.24	NS	0.041	0.009	NS	9.51	1.01
Paclobutrazole (g ai)									
P_1 (0.5)	16.48	15.36	15.92	0.28	0.286	0.28	58.78	55.28	57.03
P_2 (1.0)	16.50	15.52	16.01	0.28	0.283	0.28	59.60	56.34	57.97
P_3 (1.5)	16.49	15.38	15.94	0.28	0.273	0.28	59.06	57.07	58.07
SEm(±)	0.03	0.19	0.06	0.003	0.004	0.03	0.51	1.34	0.39
$CD_{0.05}$	NS	0.74	NS	NS	0.012	NS	NS	5.26	NS
KNO_3 (%)									
K_1 (1)	16.50	15.47	15.98	0.283	0.280	0.282	58.70	55.84	57.27
K_2 (2)	16.50	15.41	15.96	0.283	0.280	0.282	59.26	55.98	57.62
K_3 (4)	16.48	15.39	15.93	0.277	0.277	0.277	59.47	56.86	58.17
SEm(±)	0.03	0.04	0.02	0.003	0.004	0.01	0.51	0.34	0.27
$CD_{0.05}$	NS	0.08	NS	NS	0.012	NS	NS	0.66	NS
Density × Paclobutrazole (D × P)									
SEm(±)	0.05	0.39	0.23	0.005	0.017	0.01	1.03	3.85	2.24
$CD_{0.05}$	NS	1.14	NS	NS	0.051	NS	NS	11.26	NS
Density × KNO_3 (D × K)									
SEm(±)	0.05	0.08	0.13	0.005	0.012	0.01	1.03	2.77	1.61
$CD_{0.05}$	NS	0.17	NS	NS	0.035	NS	NS	8.12	NS
Paclobutrazole × KNO_3 (P × K)									
SEm(±)	0.05	0.07	0.10	0.004	0.007	0.04	0.89	1.75	0.89
$CD_{0.05}$	NS	0.15	NS	NS	0.021	NS	NS	5.26	NS
Density × Paclobutrazole × KNO_3 (D × P × K)									
SEm(±)	0.09	0.42	0.42	0.01	0.018	0.03	1.78	4.22	4.27
$CD_{0.05}$	NS	1.20	NS	NS	0.052	NS	NS	11.87	7.88
Treatments	16.55	-	16.55	0.29	-	0.29	59.15	-	59.15
Control	16.49	-	16.49	0.28	-	0.28	56.81	-	56.81
SEm(±)	0.05	-	0.05	0.00	-	0.00	0.94	-	0.94
$CD_{0.05}$	NS	-	NS	0.01	-	NS	2.61	-	1.61

NS = Non-significant

Table 5. Effect of planting density, paclobutrazole and KNO_3 on pest and disease incidence in mango cv Kesar (pooled data for 2020-21 to S2022-23)

Treatment	Stem borer incidence (%)			Powdery mildew PDI (%)		
	Rahuri	Pune	Mean	Rahuri	Pune	Mean
Planting density (m)						
D_1 (3 × 2)	12.68 (20.85)	16.41 (23.83)	14.54 (22.34)	17.46 (24.61)	20.13 (26.54)	18.80 (25.58)
D_2 (3 × 3)	9.72 (18.14)	13.96 (21.81)	11.84 (19.98)	14.72 (22.91)	16.29 (24.35)	15.50 (23.63)
D_3 (4 × 2)	7.59 (15.96)	11.59 (19.77)	9.59 (17.87)	15.42 (22.49)	17.30 (23.72)	16.36 (23.11)
D_4 (4 × 3)	7.01 (15.32)	11.35 (19.52)	9.18 (17.42)	13.44 (21.35)	14.52 (22.23)	13.98 (21.79)
SEm(±)	0.21	0.14	0.10	0.13	0.20	0.22
$CD_{0.05}$	0.57	0.41	0.61	0.36	0.56	1.42
Paclobutrazol (g ai)						
P_1 (0.5)	9.33 (17.77)	13.36 (21.33)	11.35 (19.55)	15.25 (22.27)	19.51 (26.13)	17.38 (24.41)
P_2 (1.0)	9.62 (17.46)	13.10 (21.10)	11.36 (19.28)	15.27 (22.32)	19.57 (26.22)	17.42 (24.47)
P_3 (1.5)	9.39 (17.82)	13.53 (21.47)	11.46 (19.65)	15.26 (22.30)	19.83 (26.39)	17.54 (24.61)
SEm(±)	0.18	0.13	0.01	0.11	0.17	0.21
$CD_{0.05}$	NS	0.35	NS	NS	NS	NS
KNO_3 (%)						
K_1 (1)	9.23 (17.67)	13.40 (21.36)	11.32 (19.51)	15.32 (22.92)	17.68 (24.71)	16.50 (23.82)
K_2 (2)	9.25 (17.69)	13.34 (21.31)	11.30 (19.50)	15.17 (22.80)	16.94 (24.16)	16.05 (23.48)
K_3 (4)	9.27 (17.71)	13.24 (21.22)	11.29 (19.47)	15.29 (22.90)	16.56 (23.88)	15.92 (23.39)
SEm(±)	0.18	0.13	0.03	0.11	0.17	0.21
$CD_{0.05}$	NS	NS	NS	NS	NS	NS
Density × Paclobutrazole (D × P)						
SEm(±)	0.36	0.265	0.17	0.23	0.34	0.38
$CD_{0.05}$	NS	0.71	0.56	NS	0.96	1.25
Density × KNO_3 (D × K)						
SEm(±)	0.36	0.25	0.15	0.23	0.34	0.36
$CD_{0.05}$	NS	NS	0.51	NS	NS	1.20
Paclobutrazole × KNO_3 (P × K)						
SEm(±)	0.31	0.22	0.14	0.20	0.30	1.13
$CD_{0.05}$	NS	NS	NS	NS	NS	NS
Density × Paclobutrazole × KNO_3 (D × P × K)						
SEm(±)	0.62	0.43	0.30	0.39	0.59	0.70
$CD_{0.05}$	NS	1.22	0.55	NS	NS	1.30
Treatments	8.81 (16.98)	-	8.81 (16.98)	15.08 (22.34)	-	15.08 (22.34)
Control	9.25 (17.26)	-	9.25 (17.26)	15.26 (22.56)	-	15.26 (22.56)
SEm(±)	0.33	-	0.33	0.21	-	0.21
$CD_{0.05}$	NS	-	NS	NS	-	NS

PDI = Per cent disease index, NS = Non-significant

13.98-18.80%, suggesting that most combinations remained comparable. The P × K interaction showed negligible variation, with stem borer incidence remaining around 11.35-11.46 per cent and powdery mildew around 17.38-17.54 per cent, indicating almost uniform response across treatments. The three-way interaction (D × P × K) also had minimal effect, as most treatment combinations were at par with only slight variation observed. Overall, the interaction effects were negligible, indicating that pest and disease incidence was largely unaffected by combined treatments and remained relatively stable across different combinations.

The reduction in pest and disease incidence under wider spacing may be attributed to better air circulation and light penetration within the canopy, which creates less favourable conditions for pest multiplication and fungal development. Similar observations have been reported in mango orchards where wider spacing and improved canopy management reduced disease incidence (Singh et al 2010, Solanki et al 2021). Paclobutrazol mainly regulates vegetative growth and flowering rather than directly influencing pest and disease occurrence (Burondkar and Gunjate 1993, Yeshitela et al 2004). KNO*f* primarily influences flowering and plant nutrition rather than pest or disease development (Sarker and Rahim 2013). The effect of treatments in comparison to control was also found non-significant.

Economic evaluation of planting density, paclobutrazol and KNO_3 treatments: The economic analysis clearly indicated that treatment combinations significantly influenced yield, returns and profitability of mango cv Kesar. Among all treatments, T_2 ($D_1P_1K_2$) recorded the highest yield (15.12 tonnes/ha), gross return (Rs 453,600.00), net return (Rs 323,826.09) and B-C ratio (3.50). This was closely followed by T_3 ($D_1P_1K_3$) with a B-C ratio of 3.41 and net return of Rs 317,504.45 and T_1 ($D_1P_1K_1$) with a B-C ratio of 3.33 and net return of Rs 298,582.82. The higher profitability under these treatments was mainly due to higher yield combined with relatively lower cost of cultivation. Under higher doses of paclobutrazole, the cost of cultivation increased substantially, which reduced profitability. For instance, T_7-T_9 (D_1P_3 combinations) recorded comparatively lower B-C ratios (2.24-2.29) despite similar yields (14.87-15.16 tonnes/ha) due to higher input costs. Among other planting densities, $D_3P_1K_2$ (T_{20}) performed better with a B-C ratio of 2.78 and net return of Rs 214,813.84, followed by T_{19} (2.75) and T_{21} (2.72). Similarly, under D_2, the maximum B-C ratio (2.67) was observed in T_{11} ($D_2P_1K_2$) with net return of Rs 195,151.23. The lowest profitability was recorded under wider spacing with higher input levels. Particularly, T_{36} ($D_4P_3K_3$) recorded the lowest B-C ratio (1.71) and net return (Rs 105,656.80), followed by T_{35} (1.79) and T_{34} (1.84), mainly due to lower yield (8.45-8.80 tonnes/ha) and higher cultivation costs. Overall, the results indicate that closer planting density (D_1) combined with lower dose of paclobutrazole (P_1) and moderate KNO_3 level (K_2) was the most economical, whereas, higher input levels increased cost without proportional yield gain, thereby, reducing profitability.

Similar findings of improved economic returns under high-density mango orchards with optimized growth regulator application have been reported by Solanki et al (2021) and Singh et al (2010). Among planting density treatments, combinations under D_1 (3 m × 2 m) generally produced higher economic returns due to higher yield per hectare. In contrast, treatments involving higher paclobutrazol doses increased cultivation cost and reduced the B-C ratio. For example, T_{36} ($D_4P_3K_3$) recorded the lowest B-C ratio (1.71) with a net return of Rs105,656.80, mainly due to higher input cost and comparatively lower yield. Moderate levels of growth regulators and nutrients improved profitability.

Treatments with lower paclobutrazol dose (0.5 g ai) combined with potassium nitrate produced higher net return compared with higher doses. Paclobutrazol is known to improve flowering and yield efficiency in mango orchards, thereby, increasing economic returns (Burondkar and Gunjate 1993, Yeshitela et al 2004). Similarly, potassium nitrate improves flowering and fruit set which ultimately contributes to higher productivity and profitability (Sarker and Rahim 2013). Overall, the results indicate that closer spacing (3 m × 2 m) combined with lower paclobutrazol dose and potassium nitrate application produced higher yield and economic return in mango cv Kesar under the experimental conditions.

CONCLUSION

The present study clearly demonstrated that planting density, paclobutrazol and potassium nitrate play a crucial role in improving productivity and profitability of mango cv Kesar. Closer spacing (3 m × 2 m) significantly enhanced yield per hectare despite

Table 6. Effect of planting density, paclobutrazole and KNO_3 on economics of mango cv Kesar (pooled data for 2020-21 to 2022-23)

Treatment combination	Yield (kg)	Gross return (Rs)	Cost of cultivation (Cost A) (Rs)	Additional cost (Rs)			Total cost (Rs)	Net return (Rs)	B-C ratio
				Amortization cost	Cost of P	Cost of K			
$T_1(D_1P_1K_1)$	14.23	426,900.00	65,991.00	22,083.50	38,342.65	1,900.00	128,317.18	298,582.82	3.33
$T_2(D_1P_1K_2)$	15.12	453,600.00	65,991.00	22,083.50	37,899.38	3,800.00	129,773.91	323,826.09	3.50
$T_3(D_1P_1K_3)$	14.98	449,400.00	65,991.00	22,083.50	38,121.02	5,700.00	131,895.55	317,504.45	3.41
$T_4(D_1P_2K_1)$	14.71	441,300.00	65,991.00	22,083.50	72,252.62	1,900.00	162,227.15	279,072.85	2.72
$T_5(D_1P_2K_2)$	14.50	435,000.00	65,991.00	22,083.50	73,582.43	3,800.00	165,456.96	269,543.04	2.63
$T_6(D_1P_2K_3)$	13.75	412,500.00	65,991.00	22,083.50	74,025.69	5,700.00	167,800.22	244,699.78	2.46
$T_7(D_1P_3K_1)$	14.91	447,300.00	65,991.00	22,083.50	107,714.03	1,900.00	197,688.56	249,611.44	2.26
$T_8(D_1P_3K_2)$	15.16	454,800.00	65,991.00	22,083.50	107,049.13	3,800.00	198,923.66	255,876.34	2.29
$T_9(D_1P_3K_3)$	14.87	446,100.00	65,991.00	22,083.50	105,054.43	5,700.00	198,828.96	247,271.04	2.24
$T_{10}(D_2P_1K_1)$	10.08	302,400.00	65,991.00	19,123.50	28,821.04	1,900.00	115,835.57	186,564.43	2.61
$T_{11}(D_2P_1K_2)$	10.40	312,000.00	65,991.00	19,123.50	27,934.24	3,800.00	116,848.77	195,151.23	2.67
$T_{12}(D_2P_1K_3)$	9.52	285,600.00	65,991.00	19,123.50	28,082.04	5,700.00	118,896.57	166,703.43	2.40
$T_{13}(D_2P_2K_1)$	10.31	309,300.00	65,991.00	19,123.50	54,981.68	1,900.00	141,996.21	167,303.79	2.18
$T_{14}(D_2P_2K_2)$	10.47	314,100.00	65,991.00	19,123.50	54,686.08	3,800.00	143,600.61	170,499.39	2.19
$T_{15}(D_2P_2K_3)$	10.46	313,800.00	65,991.00	19,123.50	54,390.48	5,700.00	145,205.01	168,594.99	2.16
$T_{16}(D_2P_3K_1)$	11.49	344,700.00	65,991.00	19,123.50	80,255.52	1,900.00	167,270.05	177,429.95	2.06
$T_{17}(D_2P_3K_2)$	11.39	341,700.00	65,991.00	19,123.50	79,368.72	3,800.00	168,283.25	173,416.75	2.03
$T_{18}(D_2P_3K_3)$	11.16	334,800.00	65,991.00	19,123.50	78,481.92	5,700.00	169,296.45	165,503.55	1.98
$T_{19}(D_3P_1K_1)$	10.89	326,700.00	65,991.00	19,864.90	31,096.58	1,900.00	118,852.45	207,847.55	2.75
$T_{20}(D_3P_1K_2)$	11.18	335,400.00	65,991.00	19,864.90	30,930.29	3,800.00	120,586.16	214,813.84	2.78
$T_{21}(D_3P_1K_3)$	11.08	332,400.00	65,991.00	19,864.90	30,431.41	5,700.00	121,987.28	210,412.72	2.72
$T_{22}(D_3P_2K_1)$	12.62	378,600.00	65,991.00	19,864.90	61,195.41	1,900.00	148,951.28	229,648.72	2.54
$T_{23}(D_3P_2K_2)$	12.43	372,900.00	65,991.00	19,864.90	58,867.32	3,800.00	148,523.19	224,376.81	2.51
$T_{24}(D_3P_2K_3)$	12.08	362,400.00	65,991.00	19,864.90	58,202.16	5,700.00	149,758.03	212,641.97	2.42
$T_{25}(D_3P_3K_1)$	12.61	378,300.00	65,991.00	19,864.90	83,312.23	1,900.00	171,068.10	207,231.90	2.21
$T_{26}(D_3P_3K_2)$	12.25	367,500.00	65,991.00	19,864.90	82,813.35	3,800.00	172,469.22	195,030.78	2.13
$T_{27}(D_3P_3K_3)$	11.91	357,300.00	65,991.00	19,864.90	78,323.47	5,700.00	169,879.34	187,420.66	2.10
$T_{28}(D_4P_1K_1)$	9.61	288,300.00	65,991.00	17,640.90	19,503.78	1,900.00	105,035.65	183,264.35	2.74
$T_{29}(D_4P_1K_2)$	9.36	280,800.00	65,991.00	17,640.90	19,614.59	3,800.00	107,046.46	173,753.54	2.62
$T_{30}(D_4P_1K_3)$	8.89	266,700.00	65,991.00	17,640.90	19,503.78	5,700.00	108,835.65	157,864.35	2.45
$T_{31}(D_4P_2K_1)$	9.27	278,100.00	65,991.00	17,640.90	38,785.92	1,900.00	124,317.79	153,782.21	2.24
$T_{32}(D_4P_2K_2)$	8.56	256,800.00	65,991.00	17,640.90	36,791.21	3,800.00	124,223.08	132,576.92	2.07
$T_{33}(D_4P_2K_3)$	8.74	262,200.00	65,991.00	17,640.90	39,229.18	5,700.00	128,561.05	133,638.95	2.04
$T_{34}(D_4P_3K_1)$	8.80	264,000.00	65,991.00	17,640.90	57,846.42	1,900.00	143,378.29	120,621.71	1.84
$T_{35}(D_4P_3K_2)$	8.71	261,300.00	65,991.00	17,640.90	58,178.88	3,800.00	145,610.75	115,689.25	1.79
$T_{36}(D_4P_3K_3)$	8.45	253,500.00	65,991.00	17,640.90	58,511.33	5,700.00	147,843.20	105,656.80	1.71

Price of mango: Rs 30/kg, Cost of paclobutrazol: Rs 7,990/L, Cost of KNO_3: Rs 190/kg ; D: Plant density, P: Paclobutrazole, K: KNO_3, D_1 (3 × 2 cm), D_2 (3 × 3 cm), D_3 (4 × 2 cm), D_4 (4 × 3 cm), P_1 (0.5 g ai), P_2 (1.0 g ai), P_3 (1.5 g ai), K_1 (1%), K_2 (2%), K_3

slightly lower yield per plant, highlighting the advantage of ultra high-density planting systems. Paclobutrazol proved effective in controlling vegetative growth and promoting flowering, thereby, improving yield performance, while potassium nitrate contributed to better fruit set and overall productivity. Fruit quality parameters remained relatively stable across treatments, indicating that increased productivity did not compromise fruit quality. Pest and disease incidence was marginally lower under wider spacing due to improved canopy aeration. Thus the combination of closer spacing with lower dose of paclobutrazol (0.5 g ai/tree) and moderate KNO_3 concentration (2%) was found to be the most profitable. Higher doses of inputs

increased cultivation costs without proportionate yield gains, thereby, reducing economic efficiency.

Overall, the study suggests that adoption of ultra high-density planting along with optimized use of growth regulators and nutrients can significantly enhance yield, resource use efficiency and profitability of mango cultivation under western Maharashtra conditions.

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