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Effect of Soil Application of Micronutrients on Flowering Attributes of Mango (*Mangifera indica* L.) cv. Langra

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Abstract

Present experiment was conducted during 2022-23 and 2023-24 to study the effect of soil application of micronutrients on flowering attributes of Mango (*Mangifera indica* L.) cv. Langra on 35 years old mango trees planted at Mango orchard at Matawala Bagh, School of Agricultural Sciences, Shri Guru Ram Rai University, Dehradun, Uttarakhand, India. The Experiment was laid out in randomized block design with three replications comprising of 15 treatments. The treatments combinations were M_1: Control (RDF only); M_2: RDF + Boric acid @ 250 g per tree; M_3: RDF + Zinc sulphate @ 250 g per tree; M_4: RDF + Copper sulphate @ 250 g per tree; M_5: RDF + Ferrous sulphate @ 250 g per tree; M_6: RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree; M_7: RDF + Boric acid @ 250 g per tree + Copper sulphate @ 250 g per tree; M_8: RDF + Boric acid @ 250 g per tree + Ferrous sulphate @ 250 g per tree; M_9: RDF + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree; M_{10}: RDF + Zinc sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree; M_{11}: RDF + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree; M_{12}: RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree; M_{13}: RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree; M_{14}: RDF + Boric acid @ 150 g per tree + Zinc sulphate @ 150 g per tree + Copper sulphate @ 150 g per tree + Ferrous sulphate @ 150 g per tree and M_{15}: RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree. The result revealed that among all treatments, M_{15} (RDF + Boric acid + Zinc sulphate + Copper sulphate + Ferrous sulphate @ 250 g per tree) consistently performed best across most parameters, recording maximum flowering shoots (99.94), lowest panicle malformation (0.10), earliest flowering (28.95 days), highest flowers per panicle (1144.00), staminate (290.00) and hermaphrodite flowers (1022.50), flowering shoot length (31.72 cm) and flowering intensity (78.67%).

Key words: *Mangifera indica,* Micronutrients, Boric acid, Panicle, Malformation, Flowering intensity

Mango (*Mangifera indica* L.) is one of the most important fruit crops of tropical and subtropical regions of the world and belongs to the family Anacardiaceae. It is popularly known as the "King of Fruits" due to its excellent flavour, attractive aroma, rich nutritional composition and wide consumer acceptance. Mango has been cultivated in the Indian subcontinent for more than four millennia and occupies a prominent position among fruit crops because of its economic, nutritional and cultural significance [1]. The fruit is consumed both in fresh and processed forms and serves as a valuable source of carbohydrates, vitamins, minerals, antioxidants and dietary fibre [2].

India is the largest producer of mango globally and contributes nearly 42-45 per cent of the total world production [3]. Mango is cultivated extensively in several states including Uttar Pradesh, Andhra Pradesh, Karnataka, Bihar, Gujarat, Maharashtra and West Bengal. Among the numerous cultivars grown in India, 'Langra' is one of the most popular commercial cultivars cultivated predominantly in northern India. The cultivar is highly appreciated for its fibreless pulp, pleasant aroma, superior taste and excellent processing quality [4]. However, despite its commercial importance, the productivity of mango cv. Langra remains below its potential due to several constraints including irregular flowering, poor fruit set, excessive fruit drop and nutritional imbalances [5]. Flowering is a crucial reproductive phase in mango production as it directly determines fruit set, yield and fruit quality. The success of flowering depends on a complex interaction among genetic, environmental and nutritional factors. In mango, poor panicle emergence, reduced flowering intensity, low proportion of perfect flowers and poor pollen viability frequently result in reduced fruit set and lower yields [6]. Therefore, improving flowering behaviour through efficient nutrient management is considered an important strategy for enhancing mango productivity. Plant nutrition is one of the key factors regulating growth, flowering, fruit set and yield in perennial fruit crops. While primary nutrients such as nitrogen, phosphorus and potassium are required in large quantities, micronutrients play

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equally important roles in plant metabolism despite being needed in trace amounts [7]. Micronutrients are involved in numerous physiological and biochemical processes including photosynthesis, enzyme activation, hormone synthesis, carbohydrate metabolism, protein formation and reproductive development. Deficiency of micronutrients often leads to poor vegetative growth, reduced flowering, low fruit set and inferior fruit quality [8]. Among the essential micronutrients, boron, zinc, iron and copper are particularly important for flowering and reproductive growth in mango. Boron plays a critical role in cell division, sugar translocation, pollen germination and pollen tube growth. It is directly associated with flower development, fertilization and fruit set [9]. Boron deficiency adversely affects pollen viability and results in poor fruit set and increased fruit drop [10]. Several researchers have reported that boron application improves flowering intensity, fruit retention and overall reproductive performance in fruit crops [11-12]. Zinc is another important micronutrient involved in auxin synthesis, chlorophyll formation, carbohydrate metabolism and enzyme activation. Zinc deficiency leads to impaired flower bud differentiation, poor panicle development and reduced fruit productivity [13]. Application of zinc has been reported to enhance flowering, fruit set and fruit quality in mango orchards [5], [14]. Iron is essential for chlorophyll synthesis, respiration and photosynthetic electron transport. Iron deficiency reduces photosynthetic efficiency, weakens vegetative growth and negatively affects flowering behaviour [15]. Similarly, copper participates in oxidation-reduction reactions, lignin synthesis and reproductive development, thereby contributing to healthy flower formation and improved plant vigour [6]. Micronutrient deficiencies are becoming increasingly common in mango orchards due to continuous cultivation, low organic matter content, nutrient mining and imbalanced fertilizer application. In many mango-growing regions of India, particularly under subtropical conditions, deficiencies of zinc, boron and iron have been identified as major constraints limiting productivity [1]. Such deficiencies adversely affect flowering attributes including panicle emergence, panicle size, flowering intensity, flower retention and fruit set. Micronutrients can be supplied through foliar application, fertigation and soil application. Although foliar sprays provide rapid correction of nutrient deficiencies, soil application offers long-term benefits by ensuring sustained nutrient availability and improving soil fertility status [5]. Soil applied micronutrients are absorbed through the root system and remain available for a longer duration, thereby supporting continuous physiological and reproductive processes. Furthermore, soil application is more practical in large, mature mango orchards where foliar spraying may be difficult and labour-intensive [16]. Several studies have demonstrated the beneficial effects of micronutrient application on flowering and fruiting behaviour of mango. Boron enhances pollen viability and fertilization, zinc promotes flower bud differentiation and panicle development, while iron and copper improve metabolic activity and reproductive growth [7]. Combined application of micronutrients has often been reported to produce superior results compared with individual nutrient application due to synergistic effects on plant physiology and nutrient utilization efficiency [8]. Despite considerable research on micronutrient nutrition in mango, information regarding the influence of soil-applied micronutrients on flowering attributes of mango cv. Langra under the subtropical conditions of Uttarakhand remains limited. Region specific recommendations for micronutrient management are still lacking, particularly concerning the combined application of boron, zinc, copper and iron. Therefore, systematic evaluation of soil applied micronutrients is necessary to develop effective nutrient management strategies for improving flowering behaviour and productivity of mango orchards. Considering the importance of flowering in determining fruit yield and the pivotal role of micronutrients in reproductive development, the present investigation was undertaken to evaluate the response of different soil applied micronutrients on flowering behaviour and to identify the most effective micronutrient combination for enhancing flowering performance under the subtropical conditions of Uttarakhand.

MATERIALS AND METHODS

The present investigation was made during 2022-23 and 2023-24 at the Mango Orchard of Matawala Bagh, School of Agricultural Sciences, Shri Guru Ram Rai University, Dehradun, Uttarakhand, India. Dehradun is situated at an altitude of about 640 m above mean sea level between 30.3165° N latitude and 78.0322° E longitude. The region experiences a humid subtropical climate with distinct summer, monsoon and winter seasons. Temperature ranges from about 20°C to 38°C during summer, whereas winter temperature may fall up to 3°C. The area receives an average annual rainfall of approximately 2073 mm, most of which occurs during the monsoon season. The climatic conditions of the region are favourable for mango cultivation. The experiment was carried out on healthy and uniformly maintained 35 years old mango trees of cv. Langra planted at a spacing of 10 m × 10 m. The soil of the experimental orchard was alluvial in origin, sandy loam in texture, well-drained and moderately fertile with a pH ranging from 6.35 to 6.42. Prior to the initiation of the experiment, representative soil samples were collected from the rhizosphere zone and analyzed for their physico-chemical properties using standard laboratory procedures. The experiment was laid out in a randomized block design comprising fifteen treatments with three replications. The treatments consisted of different soil applications of micronutrients either singly or in combination. The treatment details were as follows: M_1: Control (RDF only); M_2: RDF + Boric acid @ 250 g per tree; M_3: RDF + Zinc sulphate @ 250 g per tree; M_4: RDF + Copper sulphate @ 250 g per tree; M_5: RDF + Ferrous sulphate @ 250 g per tree; M_6: RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree; M_7: RDF + Boric acid @ 250 g per tree + Copper sulphate @ 250 g per tree; M_8: RDF + Boric acid @ 250 g per tree + Ferrous sulphate @ 250 g per tree; M_9: RDF + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree; M_{10}: RDF + Zinc sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree; M_{11}: RDF + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree; M_{12}: RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree; M_{13}: RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree; M_{14}: RDF + Boric acid @ 150 g per tree + Zinc sulphate @ 150 g per tree + Copper sulphate @ 150 g per tree + Ferrous sulphate @ 150 g per tree and M_{15}: RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree. The required quantities of micronutrients were applied in soil around the tree basin during the second fortnight of September in both years of experimentation. Circular trenches of approximately 20-25 cm depth and 25-30 cm width were prepared around the drip line of each tree. The calculated doses of micronutrients were weighed according to treatment requirements and applied uniformly in the trenches. For combined treatments, the micronutrients were thoroughly mixed before application to ensure uniform distribution. After application, the micronutrients were mixed with the excavated soil and the trenches were refilled. Light irrigation was provided immediately after treatment application to facilitate nutrient movement and availability within the root zone. All experimental trees received the recommended dose of farmyard manure (100 kg tree^{-1}) and NPK fertilizers (750:160:750 g per tree) as a common dose through band placement method. Recommended cultural practices including irrigation, weeding, intercultural operations, plant protection measures and orchard sanitation were uniformly followed throughout the experimental period to maintain healthy tree growth and ensure uniformity among treatments. Various flowering parameters were recorded during the flowering period. The total number of flowering shoots and malformed panicles present on each experimental tree were counted manually at full bloom stage and expressed on a per tree basis. The number of days taken for flower initiation was recorded from the emergence of new vegetative flush until the appearance of the first flower bud. For recording floral characteristics, five panicles were randomly selected and tagged on each experimental tree. The total number of flowers, staminate flowers and hermaphrodite flowers present on each tagged panicle were counted manually at full bloom stage and the average values were calculated. The length of flowering shoots was measured from the base to the tip of the panicle using a measuring scale and expressed in centimetres. Flowering intensity was determined as the percentage of flowering shoots to the total number of shoots on a tree and was calculated using the following formula:

$$\text{Flowering intensity (\%)} = \frac{\text{Number of flowering shoots}}{\text{Total number of shoots}} \times 100$$

The experimental data collected relating to different flowering parameters were statistically analyzed as described by Panse and Sukhatme [17] for interpretation of results and drawing conclusions.

Table 1 Treatment symbol with their combinations

Treatment symbol	Treatment doses
M_1	Control (as RDF)
M_2	RDF + Boric acid @ 250 g per tree
M_3	RDF + Zinc sulphate @ 250 g per tree
M_4	RDF + Copper sulphate @ 250 g per tree
M_5	RDF + Ferrous sulphate @ 250 g per tree
M_6	RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree
M_7	RDF + Boric acid @ 250 g per tree + Copper sulphate @ 250 g per tree
M_8	RDF + Boric acid @ 250 g per tree + Ferrous sulphate @ 250 g per tree
M_9	RDF + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree
M_{10}	RDF + Zinc sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree
M_{11}	RDF + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree
M_{12}	RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree
M_{13}	RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree
M_{14}	RDF + Boric acid @ 150 g per tree + Zinc sulphate @ 150 g per tree + Copper sulphate @ 150 g per tree + Ferrous sulphate @ 150 g per tree
M_{15}	RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree

RESULTS AND DISCUSSION

Flowering shoots per tree

The data pertaining to the number of flowering shoots per tree as influenced by different soil-applied micronutrient treatments have been presented in (Table 2, Fig 1) revealed that the application of micronutrients significantly influenced the number of flowering shoots per tree during both the years of investigation (2022-23 and 2023-24). During the year 2022-23, the maximum number of flowering shoots per tree (99.97) was recorded under treatment M_{15} (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was statistically at par with treatment M_{14} (99.73), comprising RDF + Boric acid @ 150 g per tree + Zinc sulphate @ 150 g per tree + Copper sulphate @ 150 g per tree + Ferrous sulphate @ 150 g per tree. These treatments were significantly superior to all other treatments. The next best treatment was M_{12} (93.97), followed by M_6 (89.80), M_8 (87.63), M_7 (87.53) and M_{13} (86.77). On the other hand, the minimum number of flowering shoots per tree (56.80) was observed under treatment M_1 (control). During the second year (2023-24), a similar trend was observed. Treatment M_{15} recorded the highest number of flowering shoots per tree (99.90), which remained statistically at par with M_{14} (99.08). Treatment M_{12} produced 95.43 flowering shoots per tree and was found significantly superior over the remaining treatments except M_{14} and M_{15}. The treatments M_8, M_{13}, M_6 and M_7 recorded 88.47, 88.37, 87.77 and 86.77 flowering shoots per tree, respectively. The lowest number of flowering shoots per tree (54.83) was recorded under treatment M_1 (control). On the basis of pooled performance over both years, treatment M_{15} recorded the highest mean number of flowering shoots per tree (99.94), followed by M_{14} (99.41) and M_{12} (94.70), whereas the minimum pooled value (55.82) was observed in M_1. The findings of the present study are in agreement with those reported by Hasani *et al.* [18], who observed that the application of zinc and other micronutrients enhanced flowering behaviour in fruit crops through improved nutrient utilization and photosynthetic activity. Gupta and Solanki [19] reported that boron plays a vital role in reproductive development, pollen formation and flower initiation, leading to increased flowering intensity under adequate boron supply. Similarly, Cakmak [20] emphasized the importance of zinc in regulating enzyme activity and auxin synthesis, which directly influence shoot growth and floral development. The results are further supported by the findings of Singh *et al.* [21], who reported significant improvement in flowering parameters following combined application of boron and zinc in fruit crops. Yadav *et al.* [22] also observed that integrated micronutrient management enhanced flowering attributes by improving photosynthetic efficiency, nutrient uptake and assimilate partitioning towards reproductive organs.

More recently, Patel *et al.* [23] reported that the combined application of boron, zinc, iron and copper significantly improved flower bud differentiation and flowering behaviour in perennial fruit crops due to their synergistic role in metabolic and reproductive processes.

Malformed panicles per tree

The data pertaining to malformed panicles per tree as influenced by different soil-applied micronutrient treatments have been presented in (Table 2, Fig 1) revealed that the application of micronutrients significantly influenced the number of malformed panicles per tree during both years of investigation (2022-23 and 2023-24). During the year 2022-23, the minimum number of malformed panicles per tree (0.07) was recorded under treatment M_{15} (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was statistically at par with treatment M_{14} (0.33), comprising RDF + Boric acid @ 150 g per tree + Zinc sulphate @ 150 g per tree + Copper sulphate @ 150 g per tree + Ferrous sulphate @ 150 g per tree. These treatments were significantly superior to all other treatments in reducing floral malformation. The next best treatment was M_{13} (1.87), followed by M_{12} (5.30), M_6 (5.47), M_8 (5.60) and M_7 (5.77). On the other hand, the maximum number of malformed panicles per tree (9.23) was observed under treatment M_1 (control). During the second year (2023-24), a similar trend was observed. Treatment M_{15} recorded the lowest number of malformed panicles per tree (0.12), which remained statistically at par with M_{14} (0.33). Treatment M_{13} recorded 1.67 malformed panicles per tree and was found significantly superior over the remaining treatments except M_{14} and M_{15}. The treatments M_{12}, M_8, M_7 and M_6 recorded 5.17, 5.33, 5.43 and 5.63 malformed panicles per tree, respectively. The highest number of malformed panicles per tree (9.63) was recorded under treatment M_1 (control). On the basis of pooled performance over both years, treatment M_{15} recorded the lowest mean number of malformed panicles per tree (0.10), followed by M_{14} (0.33) and M_{13} (1.77), whereas the maximum pooled value (9.43) was observed in M_1. Among the individual micronutrient treatments, boric acid alone (M_2) was more effective in reducing panicle malformation, recording pooled values of 6.42 malformed panicles per tree compared with zinc sulphate (8.28), copper sulphate (8.00) and ferrous sulphate (7.90). Recent studies have highlighted the importance of micronutrient management in reducing floral abnormalities and improving reproductive efficiency in mango. Singh *et al.* [21] reported that balanced micronutrient nutrition significantly improved flowering behaviour and reduced physiological disorders in fruit crops by enhancing nutrient metabolism and hormonal balance. Kumar *et al.* [4] observed that the combined application of boron and zinc improved floral health and reduced the incidence of malformed inflorescences through enhanced assimilate translocation and reproductive growth. Similarly, Deb and Reza [24] reported that boron and zinc application before flowering improved panicle emergence and flower development in mango, which was attributed to improved nutritional and physiological status of trees. The present findings also agree with the observations of Yadav *et al.* [22], reported that integrated micronutrient management improved flowering characteristics and reduced floral abnormalities through enhanced photosynthetic efficiency and enzyme activity. Kuldeep *et al.* [25] demonstrated that the integrated application of micronutrients, along with growth-promoting inputs, effectively reduced panicle malformation and improved floral health in mango by maintaining balanced nutrient status and normal reproductive development.

Table 2 Effect of soil application of micronutrients on number of flowering shoots per tree, malformed panicles per tree, days taken to flower initiation and number of flowers per panicle of mango

Treatment	Flowering shoots/tree		Malformed panicles/tree		Days taken to flower initiation		Number of flowers per panicle	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
M_1	56.80	54.83	9.23	9.63	36.80	37.10	871	866
M_2	82.00	83.70	6.50	6.33	34.50	34.80	870	867
M_3	62.97	62.67	8.23	8.33	35.20	35.50	891	894
M_4	72.03	73.57	8.07	7.93	35.80	35.60	895	893
M_5	70.67	74.20	7.90	7.90	35.40	35.20	928	917
M_6	89.80	87.77	5.47	5.63	32.80	33.10	904	903
M_7	87.53	86.77	5.77	5.43	33.10	33.40	913	717
M_8	87.63	88.47	5.60	5.33	32.90	33.00	899	894
M_9	80.40	78.73	7.57	7.63	34.10	34.30	913	913
M_{10}	77.10	77.83	7.57	7.63	33.90	34.10	986	983
M_{11}	79.60	80.90	7.77	7.60	34.00	34.20	1005	1007
M_{12}	93.97	95.43	5.30	5.17	31.20	31.50	1009	1010
M_{13}	86.77	88.37	1.87	1.67	30.80	31.10	1122	1094
M_{14}	99.73	99.08	0.33	0.33	29.40	29.70	1054	1092
M_{15}	99.97	99.90	0.07	0.12	28.80	29.10	1130	1158
C.D.$_{(p=0.05)}$	2.69	2.51	2.69	0.42	**1.42**	**1.36**	**1.42**	2.76
S.Em.±	0.92	0.87	0.92	0.14	**0.49**	**0.47**	**0.49**	0.95

Days taken to flower initiation

The data on days taken to flower initiation have been presented in (Table 2, Fig 1) revealed that soil application of micronutrients significantly influenced the days taken to flower initiation during both years of experimentation (2022-23 and 2023-24). During the year 2022-23, the minimum number of days taken for flower initiation (28.80 days) was recorded under treatment **M_{15}** (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was found statistically at par with treatment M_{14} (29.40 days). The next best treatments were M_{13} (30.80 days) and M_{12} (31.20 days), followed by M_6 (32.80 days), M_8 (32.90 days) and M_7 (33.10 days). However, treatments M_{10}, M_{11} and M_9 recorded 33.90, 34.00 and 34.10 days, respectively. Among the individual micronutrient treatments, M_2 (34.50 days) was superior to M_3 (35.20 days), M_5 (35.40 days) and M_4 (35.80 days). The maximum number of days taken for flower initiation (36.80

days) was observed under M_1 (control). A similar trend was observed during the year 2023-24. Treatment M_{15} recorded the earliest flower initiation requiring only 29.10 days, which remained statistically at par with M_{14} (29.70 days). Treatment M_{13} required 31.10 days for flower initiation, followed by M_{12} (31.50 days). The treatments M_8, M_6 and M_7 recorded 33.00, 33.10 and 33.40 days, respectively. Treatments M_{10}, M_{11} and M_9 required 34.10, 34.20 and 34.30 days for flower initiation, respectively. Among the individual micronutrient applications, treatment M_2 (34.80 days) was found superior to M_5 (35.20 days), M_3 (35.50 days) and M_4 (35.60 days). The maximum number of days taken for flower initiation (37.10 days) was recorded under M_1 (control), which was significantly higher than all other treatments. On the basis of pooled performance over both years, treatment M_{15} recorded the minimum mean number of days taken for flower initiation (28.95 days), followed by M_{14} (29.55 days), M_{13} (30.95 days) and M_{12} (31.35 days). Conversely, the maximum pooled value (36.95 days) was observed under treatment M_1 (control). The present findings are in close agreement with those reported by Kumar and Singh [26], who observed that integrated micronutrient management accelerated flowering in fruit crops by improving physiological efficiency and nutrient utilization. Sharma *et al.* [27] reported earlier flower emergence following boron and zinc application, attributing the response to improved carbohydrate metabolism and hormonal regulation. Similar observations were made by Meena *et al.* [28], who reported that balanced micronutrient nutrition enhanced floral induction and reduced the time required for flowering through increased photosynthetic activity and nutrient translocation. Recent studies have further highlighted the importance of micronutrients in regulating flowering behaviour. Patel *et al.* [23] reported that combined application of boron, zinc and iron significantly advanced flowering in horticultural crops by improving enzymatic activity and assimilate partitioning. Likewise, Verma *et al.* [29] observed that integrated micronutrient application promoted earlier reproductive development by enhancing nutrient uptake efficiency and physiological vigour of fruit trees. Similar conclusions were drawn by Choudhary *et al.* [30], who reported that balanced micronutrient supplementation improved floral initiation and synchronization of flowering through enhanced metabolic activity and reproductive efficiency.

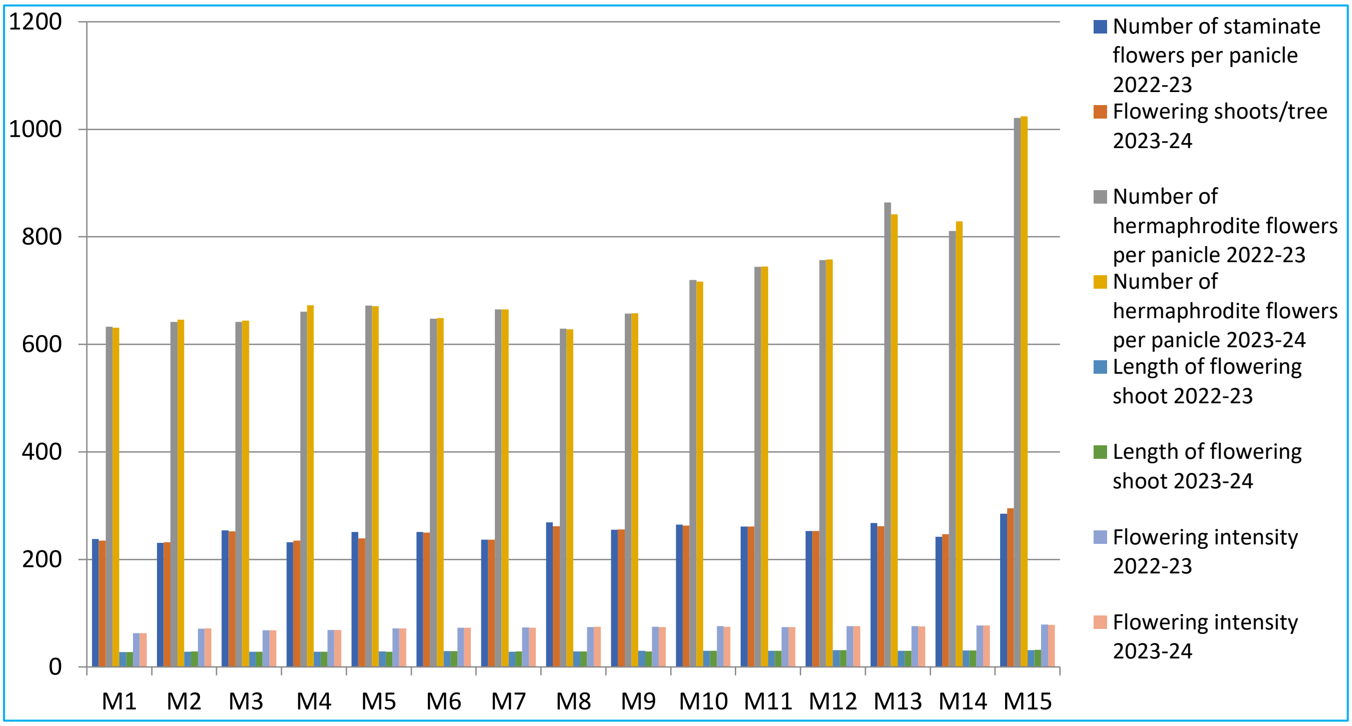

Fig 1 Effect of soil application of micronutrients on number of flowering shoots per tree, malformed panicles per tree, days taken to flower initiation and number of flowers per panicle of mango

Number of flowers per panicle

The data on number of flowers per panicle was influenced by different treatments have presented in (Table 2, Fig 1). The data revealed that the application of micronutrients significantly influenced the number of flowers per panicle during both years of investigation (2022-23 and 2023-24). The results indicated that during the year 2022-23, the maximum number of flowers per panicle (1130) was recorded under treatment M15 (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was found significantly superior over all other treatments. The next highest number of flowers per panicle (1122) was observed under treatment M13, followed by M14 (1054), M12 (1009) and M11 (1005). Treatment M10 recorded 986 flowers per panicle. Among the dual micronutrient combinations, treatments M7 and M9 each recorded 913 flowers per panicle, followed by M6 (904) and M8 (899). Among the individual micronutrient treatments, M5 (Ferrous sulphate @ 250 g per tree) produced the highest number of flowers per panicle (928), followed by M4 (895), M3 (891) and M2 (870). The minimum number of flowers per panicle (871) was observed under M1 (control). A similar trend was observed during the year 2023-24. Treatment M15 recorded the maximum number of flowers per panicle (1158), which was significantly superior to all other treatments. The next best treatments were M13 (1094) and M14 (1092), followed by M12 (1010) and M11 (1007). Treatment M10 produced 983 flowers per panicle. Among the dual micronutrient combinations, M9 recorded 913 flowers per panicle, followed by M6 (903), M3 and M8 (894 each) and M4 (893). Among the individual micronutrient treatments, M5 recorded 917 flowers per panicle, whereas M2 produced 867 flowers per panicle. The minimum number of flowers per panicle (717) was recorded under M7, while the control treatment M1 recorded 866 flowers per panicle. On the basis of pooled performance over both years, treatment M15 recorded the highest mean number of flowers per panicle (1144.00), followed by M13 (1108.00), M14 (1073.00), M12 (1009.50) and M11 (1006.00). The lowest pooled value (794.00) was observed under treatment M7, while the control treatment M1 recorded a pooled mean of 868.50 flowers per panicle. The present findings are supported by the observations of Kaur *et al.* [31], who reported that balanced micronutrient nutrition significantly increased flower production in fruit crops through enhanced nutrient utilization and reproductive development. Similarly, Kumar *et al.* [32] observed that the combined application of boron and zinc improved floral attributes, including the number of flowers per inflorescence, owing to improved carbohydrate metabolism and flower bud differentiation. Meena *et al.* [28] reported that micronutrient supplementation enhanced floral intensity and inflorescence development by improving physiological efficiency and photosynthetic activity in perennial fruit crops. Recent investigations by Patel *et al.* [23] demonstrated that integrated micronutrient management significantly increased flower density and reproductive success through improved enzymatic activity and nutrient translocation. Verma *et al.* [29] reported that combined application of essential micronutrients enhanced floral development and increased the number of flowers per panicle by maintaining optimum nutrient balance and metabolic activity. Choudhary *et al.* [30] concluded that micronutrient-mediated improvement in reproductive growth was associated with enhanced assimilate partitioning and efficient utilization of photosynthetic products during flowering.

Table 3 Effect of soil application of micronutrients on number of staminate flowers per panicle, number of hermaphrodite flowers per panicle, length of flowering shoot and flowering intensity of mango

Treatment	Number of staminate flowers per panicle		Number of hermaphrodite flowers per panicle		Length of flowering shoot (cm)		Flowering intensity (%)	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
M_1	238	235	633	631	27.83	27.77	63.00	62.67
M_2	231	232	642	646	28.30	28.60	71.00	71.67
M_3	254	252	642	644	28.27	28.27	68.33	68.00
M_4	232	235	661	673	28.27	28.30	69.00	68.67
M_5	251	239	672	671	28.57	28.13	72.00	71.67
M_6	251	250	648	649	29.50	29.40	72.67	73.00
M_7	237	237	665	665	28.37	28.77	73.67	73.00
M_8	269	262	629	628	28.70	28.77	74.33	75.00
M_9	255	256	657	658	29.80	28.90	74.67	74.33
M_{10}	265	263	720	717	29.90	29.80	76.00	75.00
M_{11}	261	261	744	745	30.00	29.90	74.33	74.00
M_{12}	253	253	757	758	31.13	31.33	75.67	75.67
M_{13}	268	262	864	842	30.23	29.97	75.67	75.33
M_{14}	242	247	811	829	30.77	30.37	77.00	77.33
M_{15}	285	295	1021	1024	31.43	32.00	79.00	78.33
C.D.$_{(p=0.05)}$	**1.42**	3.31	**1.42**	5.23	**1.42**	0.43	**1.42**	1.71
S.Em.±	**0.49**	1.15	**0.49**	1.80	**0.49**	0.15	**0.49**	0.58

Number of staminate flowers per panicle

Data pertaining to the number of staminate flowers per panicle have been presented in (Table 3, Fig 2) revealed that the application of micronutrients significantly influenced the number of staminate flowers per panicle during both years of investigation (2022-23 and 2023-24). During the year 2022-23, the maximum number of staminate flowers per panicle (285) was recorded under treatment M15 (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was significantly superior to all other treatments. The next highest number of staminate flowers per panicle was observed under treatment M8 (269), followed closely by M13 (268) and M10 (265). Treatments M11, M9, M3 and M12 recorded 261, 255, 254 and 253 staminate flowers per panicle, respectively. Treatments M5 and M6 each produced 251 staminate flowers per panicle. Treatment M14 recorded 242 staminate flowers per panicle, while M1 (control) and M7 produced 238 and 237 staminate flowers per panicle, respectively. The minimum number of staminate flowers per panicle (231) was observed under treatment M2 (RDF + Boric acid @ 250 g per tree). During the year 2023-24, a similar trend was observed. Treatment M15 recorded the highest number of staminate flowers per panicle (295), which was significantly superior to all other treatments. The next best treatment was M10 (263), followed by M8 and M13 (262 each) and M11 (261). Treatments M9, M12, M3 and M6 recorded 256, 253, 252 and 250 staminate flowers per panicle, respectively. Treatment M14 produced 247 staminate flowers per panicle, whereas M5, M7, M1 and M4 recorded 239, 237, 235 and 235 staminate flowers per panicle, respectively. The lowest number of staminate flowers per panicle (232) was observed under treatment M2, followed by M4 and M1. On the basis of pooled performance over both years, treatment M15 recorded the highest mean number of staminate flowers per panicle (290.00), followed by M8 (265.50), M13 (265.00) and M10 (264.00). Treatments M11 (261.00), M9 (255.50) and M12 (253.00) also performed well. The minimum pooled value (231.50) was recorded under treatment M2, followed by M4 (233.50) and M1 (236.50). The results obtained in the present investigation are in agreement with the findings of Jat *et al.* [33], who reported that integrated micronutrient application significantly influenced floral characteristics and flower production in fruit crops through improved nutrient metabolism and reproductive growth. Similarly, Saini *et al.* [34] observed an increase in flower density and floral development following micronutrient supplementation, which was attributed to enhanced physiological efficiency and assimilate accumulation.

Bhargava and Sharma [35] reported that balanced micronutrient nutrition improved panicle development and flower production in mango by stimulating meristematic activity and floral differentiation. The present findings supported by Tiwari *et al.* [36], who observed that combined application of zinc, boron and iron enhanced inflorescence development and increased floral abundance in subtropical fruit crops. Khan *et al.* [37] reported that micronutrient-induced improvements in photosynthetic efficiency and nutrient translocation promoted flower formation and reproductive growth. Reddy *et al.* [38] concluded that integrated micronutrient management significantly improved floral architecture and flower production by maintaining optimum physiological and nutritional conditions during the flowering period.

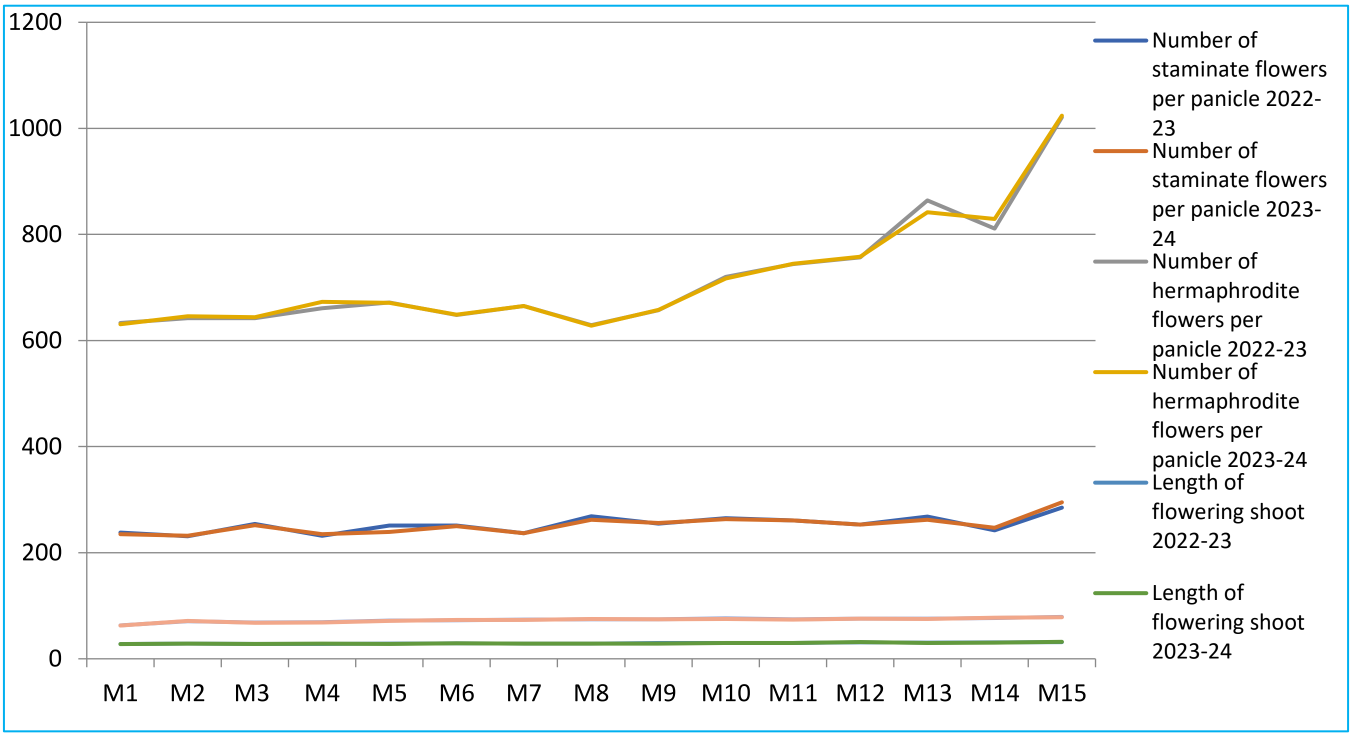

Fig 2 Effect of soil application of micronutrients on number of staminate flowers per panicle, number of hermaphrodite flowers per panicle, length of flowering shoot and flowering intensity of mango

Number of hermaphrodite flowers per panicle

The data pertaining to the number of hermaphrodite flowers per panicle have been presented in (Table 3, Fig 2). The data revealed that the application of micronutrients significantly influenced the number of hermaphrodite flowers per panicle during both years of investigation (2022-23 and 2023-24). During the year 2022-23, the maximum number of hermaphrodite flowers per panicle (1021) was recorded under treatment M15 (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was significantly superior to all other treatments. The next highest number of hermaphrodite flowers per panicle was observed under treatment M13 (864), followed by M14 (811), M12 (757) and M11 (744). Treatments M10, M5 and M7 recorded 720, 672 and 665 hermaphrodite flowers per panicle, respectively. Treatments M4 (661) and M9 (657) also performed better than the control. Among the individual micronutrient treatments, treatment M5 (Ferrous sulphate @ 250 g per tree) recorded the highest number of hermaphrodite flowers per panicle (672), followed by M4 (661), M3 and M2 (642 each). The minimum number of hermaphrodite flowers per panicle (629) was observed under treatment M8, followed closely by M1 (633). During the year 2023-24, a similar trend was observed. Treatment M15 recorded the highest number of hermaphrodite flowers per panicle (1024), which was significantly superior to all other treatments. The next best treatment was M13 (842), followed by M14 (829), M12 (758) and M11 (745). Treatments M10, M4 and M5 recorded 717, 673 and 671 hermaphrodite flowers per panicle, respectively. Treatments M7 (665) and M9 (658) also showed higher values than the control. Among the individual micronutrient treatments, M5 recorded 671 hermaphrodite flowers per panicle, followed by M4 (673), M2 (646) and M3 (644). The minimum number of hermaphrodite flowers per panicle (628) was recorded under treatment M8, whereas the control treatment M1 recorded 631 hermaphrodite flowers per panicle. On the basis of pooled performance over both years, treatment M15 recorded the highest mean number of hermaphrodite flowers per panicle (1022.50), followed by M13 (853.00), M14 (820.00), M12 (757.50) and M11 (744.50). Treatments M10 (718.50), M5 (671.50) and M4 (667.00) also exhibited comparatively higher pooled values. The minimum pooled value (628.50) was observed under treatment M8, followed by M1 (632.00). The findings of the present investigation are in agreement with those of Mishra *et al.* [39], who reported that micronutrient supplementation significantly improved the proportion of hermaphrodite flowers in fruit crops by enhancing reproductive tissue development and nutrient utilization. Likewise, Rajput *et al.* [40] observed that balanced application of boron and zinc increased the number of perfect flowers through improved floral differentiation and hormonal regulation. Kumari and Prasad [41] also reported that micronutrient nutrition positively influenced flower sex expression and reproductive behaviour in perennial fruit crops. Further support is provided by the findings of Narayan *et al.* [42], who reported that integrated micronutrient management enhanced hermaphrodite flower production by improving assimilate partitioning and floral organ development. Singh and Rathore [43] observed a significant increase in reproductive flower formation following the combined application of micronutrients, attributing the response to improved metabolic activity and reproductive physiology. More recently, Joshi *et al.*

[44] concluded that balanced micronutrient nutrition enhanced floral quality and reproductive success by promoting normal development of both male and female reproductive structures within the flower.

Length of flowering shoot (cm)

The data pertaining to the length of flowering shoot as influenced by different soil-applied micronutrient treatments have been presented in (Table 3, Fig 2). The data revealed that the application of micronutrients significantly influenced the length of flowering shoots during both years of investigation (2022-23 and 2023-24). During the year 2022-23, the maximum length of flowering shoot (31.43 cm) was recorded under treatment M15 (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was found statistically at par with treatment M12 (31.13 cm) and M14 (30.77 cm). These treatments were significantly superior to all other treatments. The next best treatment was M13 (30.23 cm), followed by M11 (30.00 cm), M10 (29.90 cm) and M9 (29.80 cm). Whereas, treatments M6, M8 and M5 recorded flowering shoot lengths of 29.50, 28.70 and 28.57 cm, respectively. Among the individual micronutrient treatments, M2 recorded a flowering shoot length of 28.30 cm, while M3 and M4 each recorded 28.27 cm. The minimum length of flowering shoot (27.83 cm) was observed under M1 (control). During the second year (2023-24), a similar trend was observed. Treatment M15 recorded the maximum flowering shoot length (32.00 cm), which was significantly superior to all other treatments. The next highest flowering shoot length was recorded under M12 (31.33 cm), followed by M14 (30.37 cm) and M13 (29.97 cm). Treatments M11, M10 and M6 produced flowering shoot lengths of 29.90, 29.80 and 29.40 cm, respectively. However, treatments M9 (28.90 cm), M7 (28.77 cm) and M8 (28.77 cm) also showed improved flowering shoot length over the control. Among the individual micronutrient treatments, M2 recorded 28.60 cm, followed by M4 (28.30 cm), M3 (28.27 cm) and M5 (28.13 cm). The minimum flowering shoot length (27.77 cm) was recorded under M1 (control). On the basis of pooled performance over both years, treatment M15 recorded the highest mean flowering shoot length (31.72 cm), followed by M12 (31.23 cm), M14 (30.57 cm) and M13 (30.10 cm). Treatments M11 (29.95 cm), M10 (29.85 cm) and M9 (29.35 cm) also performed well. Whereas, the minimum pooled flowering shoot length (27.80 cm) was observed under M1 (control). The findings of the present study are in close conformity with those reported by Chauhan *et al.* [45], who observed that micronutrient application significantly improved shoot growth and reproductive branch development in fruit crops through enhanced physiological activity. Similarly, Barman *et al.* [46] reported increased shoot elongation following integrated micronutrient application, attributing the response to improved nutrient utilization and photosynthetic performance. Das and Sahoo [47] also reported that adequate supply of micronutrients promoted vegetative and reproductive shoot growth by stimulating cellular expansion and metabolic activity. Recent studies by Khandelwal *et al.* [48] revealed that combined application of boron, zinc and iron improved reproductive shoot development and flowering characteristics in perennial fruit crops. Likewise, Nirmal *et al.* [49] reported that balanced micronutrient nutrition enhanced shoot elongation and canopy productivity through improved enzyme activity and assimilate translocation. The findings are further corroborated by Rao *et al.* [50], who concluded that integrated micronutrient management significantly improved reproductive shoot growth and flowering efficiency by maintaining optimum nutritional and physiological conditions throughout the flowering period.

Flowering intensity (%)

The data pertaining to flowering intensity (%) as influenced by different soil-applied micronutrient treatments have been presented in (Table 3, Fig 2). The data revealed that the application of micronutrients significantly influenced flowering intensity during both years of investigation (2022-23 and 2023-24). During the year 2022-23, the maximum flowering intensity (79.00%) was recorded under treatment M15 (RDF + Boric acid @ 250 g per tree + Zinc sulphate @ 250 g per tree + Copper sulphate @ 250 g per tree + Ferrous sulphate @ 250 g per tree), which was found significantly superior to all other treatments. The next highest flowering intensity (77.00%) was observed under treatment M14 (RDF + Boric acid @ 150 g per tree + Zinc sulphate @ 150 g per tree + Copper sulphate @ 150 g per tree + Ferrous sulphate @ 150 g per tree). Treatments M10 (76.00%), M12 (75.67%) and M13 (75.67%) also recorded significantly higher flowering intensity. Treatments M9, M8 and M11 recorded flowering intensities of 74.67, 74.33 and 74.33 per cent, respectively. The treatments M7 (73.67%), M6 (72.67%), M5 (72.00%) and M2 (71.00%) were found superior to the control. Among the individual micronutrient treatments, M5 (Ferrous sulphate @ 250 g per tree) recorded the highest flowering intensity (72.00%), followed by M2 (71.00%), M4 (69.00%) and M3 (68.33%). The minimum flowering intensity (63.00%) was recorded under M1 (control). During the second year (2023-24), a trend similar to the first year was observed. Treatment M15 recorded the highest flowering intensity (78.33%), which was significantly superior to all other treatments. Treatment M14 ranked second with 77.33% flowering intensity. Treatments M12 (75.67%), M13 (75.33%), M8 (75.00%) and M10 (75.00%) also exhibited higher flowering intensity. Treatments M9, M11, M6 and M7 recorded flowering intensities of 74.33, 74.00, 73.00 and 73.00 per cent, respectively. Among the individual micronutrient treatments, M2 and M5 each recorded 71.67% flowering intensity, followed by M4 (68.67%) and M3 (68.00%). The lowest flowering intensity (62.67%) was observed under M1 (control). On the basis of pooled performance over both years, treatment M15 recorded the highest mean flowering intensity (78.67%), followed by M14 (77.17%), M12 (75.67%), M13 (75.50%) and M10 (75.50%). Treatments M8 (74.67%), M9 (74.50%) and M11 (74.17%) also exhibited comparatively higher flowering intensity. The minimum pooled flowering intensity (62.84%) was observed under M1 (control), whereas among the individual micronutrient applications, M5 recorded the highest pooled value (71.84%). The results obtained in the present study are supported by the findings of Dutta *et al.* [51], who reported that balanced micronutrient nutrition significantly enhanced flowering intensity in fruit crops by improving assimilate accumulation and reproductive development. Similarly, Elango *et al.* [52] observed that integrated micronutrient application increased the proportion of flowering shoots through improved nutrient uptake and metabolic activity. Ghosh and Roy [53] also reported that micronutrient supplementation enhanced flowering behaviour in perennial fruit crops by promoting floral bud differentiation and physiological efficiency. Further support comes from the work of Mahawar *et al.* [54], who demonstrated that combined application of essential micronutrients significantly improved flowering intensity and flowering regularity through enhanced carbohydrate metabolism and nutrient translocation. In a recent study, Bisen *et al.* [55] reported that micronutrient-induced improvements in photosynthetic performance and assimilate partitioning resulted in higher flowering intensity and reproductive potential. Likewise, Prakash *et al.* [56] concluded that integrated micronutrient management promoted floral induction and increased flowering intensity by maintaining favourable nutritional and biochemical conditions during the pre-flowering period.

CONCLUSION

The present investigation clearly demonstrated that soil application of micronutrients significantly influenced the flowering attributes of mango (*Mangifera indica* L.) cv. Langra under subtropical conditions of Uttarakhand. Among all the treatments, the combined application of boric acid @ 250 g tree^{-1}, zinc sulphate @ 250 g tree^{-1}, copper sulphate @ 250 g tree^{-1} and ferrous sulphate @ 250 g tree^{-1} along with the recommended dose of fertilizers (M15) proved to be the most effective treatment. This treatment recorded the highest number of flowering shoots per tree (99.94), flowers per panicle (1144.00), staminate flowers per panicle (290.00), hermaphrodite flowers per panicle (1022.50), flowering shoot length (31.72 cm) and flowering intensity (78.67%). It also resulted in the minimum number of malformed panicles per tree (0.10) and the earliest flower initiation (28.95 days). Therefore, the integrated soil application of these micronutrients along with RDF can be recommended for improving flowering behaviour and reproductive efficiency of mango cv. Langra under subtropical agro-climatic conditions.

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