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Influence of managed bee pollination and attractants on yield and seed quality of safflower (*Carthamus tinctorius* L.)

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Abstract

Safflower (*Carthamus tinctorius* L.) is an important *rabi* oilseed crop cultivated under rainfed and irrigated conditions in arid and semi-arid regions of India. Although considered self-pollinated, its floral biology and capitulum structure greatly benefit from insect pollination. A field experiment was conducted during the *rabi* season of 2025-26 at the Agricultural College Farm, Bapatla andhra Pradesh, to evaluate the influence of managed bee pollination and various foliar attractants on the yield, seed quality and oil content of safflower (variety Lakshmi Priya / ISF-764). The experiment was laid out in a Randomized Block Design with three replications and seven treatments: open pollination (T₁), plots caged with managed *Apis mellifera* Linnaeus colony (T₂), pollinator exclusion via caging (T₃), foliar spray of 50% sugar solution (T₄), foliar spray of 50% jaggery solution (T₅), foliar spray of commercial bee attractant PARI @ 4 ml L⁻¹ (T₆) and foliar spray of water (T₇). The results revealed that managed bee pollination (T₂) recorded the highest value for most parameters, including seeds per capitulum (33.95), capitulum weight (2.96 g), percentage of filled seeds (31.94), seed set percentage (84.14%), seed filling percentage (94.18%), seed yield per plant (42.56 g) and seed yield per hectare (2456.04 kg ha⁻¹). Among the attractants, foliar spray of 50% sugar solution (T₄) proved superior, resulting in a seed yield of 2256.21 kg ha⁻¹, which represents a significant improvement over open pollination (2163.23 kg ha⁻¹). Conversely, the minimum values for seeds per capitulum (24.68), filled seeds (17.92), seed set (65.90%), seed filling (74.60%) and seed yield (1995.36 kg ha⁻¹) were observed in pollinator-excluded plots (T₃). Furthermore, seeds harvested from T₂ produced superior seedlings with the highest vigour index (1054.51) and seedling vigour (11.26), which was significantly superior to pollinator exclusion (500.29 and 5.84). The parameters capitula per plant, thousand-seed test weight, germination percentage and oil content did not vary significantly among the treatments, indicating that these attributes are predominantly genetically controlled. However, managed bee pollination and attractants numerically enhanced these parameters. The study highlights the crucial ecosystem service provided by honey bees and suggests the utility of managed bee colonies and sugar solution sprays in maximizing safflower yield and quality.

Keywords: *Apis mellifera*, bee attractants, *Carthamus tinctorius*, seed filling, seedling vigour index and safflower yield

Introduction

Safflower (*Carthamus tinctorius* L.) is an important *rabi* oilseed crop belonging to the family Asteraceae. It is believed to have originated in the Middle East and has been cultivated since ancient times for edible oil, medicinal purposes and natural dyes (Azeez *et al.*, 2017) [3]. The crop is widely adapted to arid and semi-arid regions because of its drought tolerance and deep root system. In India, safflower is mainly cultivated in Maharashtra, Karnataka, Telangana andhra Pradesh and parts of Madhya Pradesh under rainfed conditions. Safflower occupies an important position among *rabi* oilseed crops because of its ability to produce stable yields under moisture stress conditions. The seeds are highly valued for their nutritional quality and contain about 28-38 per cent oil rich in polyunsaturated fatty acids, especially linoleic acid, which is beneficial to human health. Safflower oil is considered a premium quality edible oil due to its low saturated fat content and high oxidative stability. Apart from edible uses, safflower oil finds applications in pharmaceuticals, cosmetics, paints and industrial products. The petals of safflower flowers contain colouring pigments such as carthamin and are traditionally used as dyes and herbal medicines.

The crop residues and seed cake are also utilized as animal feed because of their protein content (Singh and Mishra, 2019) [30].

Pollination is one of the most important biological processes in flowering plants and plays a major role in improving agricultural productivity. More than 75 per cent of flowering plants and nearly one-third of global crop production depend upon insect pollination either directly or indirectly (Roubik, 1995) [27]. Insect pollination not only increases crop yield but also improves seed quality, seed viability, oil content and uniformity in maturity. Among various insect pollinators, honey bees are considered the most efficient and economically important pollinating agents because of their flower constancy, foraging efficiency and ability to visit a large number of flowers within a short period (Winston, 1987) [31].

Although safflower is generally considered a self-pollinated crop, its floral morphology favours considerable cross-pollination through insects. The capitulum consists of numerous hermaphrodite, tubular florets that open progressively from the periphery to the center. Anthesis generally occurs during morning hours and the stigma becomes receptive shortly after. During foraging, bees facilitate the transfer of pollen grains from one floret to another, thereby increasing fertilization and seed set (Free, 1993) [8]. Studies have indicated that bee pollination in safflower significantly improves the number of filled seeds, seed weight, oil content and overall crop productivity (Panda *et al.*, 1988) [19]. Managed pollination using European honey bees (*Apis mellifera* L.) has emerged as a reliable method to improve agricultural productivity. However, the activity of bees is heavily dependent on the floral resource density and environmental factors. To enhance bee activity on crops, chemical bee attractants have been evaluated. Bee attractants are substances capable of increasing the number of bee visits to flowers by stimulating their foraging behavior. Sugar-based formulations, jaggery solutions and commercial formulations like PARI have been used in various crops to enhance pollination and improve yields (Roubik, 1995; Kishanrao, 2001) [27, 11].

While several studies have assessed insect visitor diversity on safflower, comprehensive investigations comparing managed bee pollination, open pollination, pollinator exclusion and foliar sprays of bee attractants on yield attributes and physiological seed parameters are limited. Understanding these effects is essential for designing sustainable crop production practices and maximizing safflower yields. Therefore, the present investigation was undertaken to study the influence of pollination on the yield and quality parameters of safflower under the agro-climatic conditions of Bapatla andhra Pradesh, India.

Materials and Methods

The field experiment was conducted during the *rabi* season of 2025-26 at the Agricultural College Farm, Bapatla andhra Pradesh, India. The experimental site is situated at an altitude of 8 m above MSL, 15.922° N latitude and 80.480° E longitude, receiving an average annual rainfall of 914 mm. The soil of the experimental field was sandy clay loam in texture and sowing was done under irrigated conditions. The safflower variety used for the study was “Lakshmi Priya” (ISF-764), which is widely adapted to dryland and irrigated *rabi* farming systems. The seed material was procured from the ICAR-Indian Institute of Oil Seeds Research (IIOR), Rajendranagar, Hyderabad.

The experiment was laid out in a Randomized Block Design (RBD) with three replications. The individual plot size measured 5.4 m × 4.0 m and sowing was done manually at a row-to-row spacing of 45 cm and plant-to-plant spacing of 20 cm, utilizing a seed rate of 8 kg ha⁻¹. Standard agronomic practices, excluding chemical plant protection measures during the flowering period, were adopted to raise the crop. Half of the recommended nitrogen (30 kg ha⁻¹) and the full dose of phosphorus (30 kg ha⁻¹) and potassium (20 kg ha⁻¹) were applied as basal doses during the final land preparation and the remaining half of nitrogen was top-dressed in two equal splits at 30 and 55 days after sowing (DAS). The study evaluated seven distinct pollination treatments, detailed as follows:

Treatment	Treatment Description
T ₁ - Open Pollination	Plots were kept open to natural insect pollinators throughout the crop growth period.
T ₂ - Nylon Net with <i>Apis mellifera</i>	Plots were enclosed with insect-proof nylon nets (2 mm mesh size) at the onset of flowering and a managed four-frame colony of <i>Apis mellifera</i> with a prolific queen and adequate worker population was introduced inside each enclosure.
T ₃ - Pollinator Exclusion (Nylon Net)	Plots were covered with insect-proof nylon nets before flowering to exclude all insect pollinators throughout the flowering period.
T ₄ - Sugar Solution (50%)	Plots were sprayed once with a 50% sugar solution at 25% flowering during the morning hours (08:00 h) to attract pollinators.
T ₅ - Jaggery Solution (50%)	Plots were sprayed once with a 50% jaggery solution at 25% flowering during the morning hours (08:00 h) to attract pollinators.
T ₆ - Bee Attractant (PARI)	Plots were sprayed once with the commercial bee attractant PARI (Yash Udyog, Ahmednagar, Maharashtra) at 4 mL L ⁻¹ of water at 25% flowering.
T ₇ - Water Spray	Plots were sprayed once with distilled water at 25% flowering during the morning hours (08:00 h) to serve as the foliar spray control.

Observations on yield parameters were recorded from twenty-five randomly selected plants in each replication per treatment before and after harvest. The parameters studied were: number of capitula per plant, number of seeds per capitulum, average capitulum weight (g), number of filled and unfilled seeds per capitulum, seed set percentage and seed filling percentage.

Seed set percentage was calculated using the formula:

Seed setting (%) = (Number of filled seeds per capitulum / Total number of florets per capitulum) × 100

Seed filling percentage was determined by dissecting seeds from

the twenty-five selected capitula. At harvest, seed yield per plant was measured in grams and total plot yield was converted and expressed as seed yield per hectare (kg ha⁻¹).

Seed quality parameters were evaluated post-harvest. The test weight was recorded by weighing 1000 clean seeds on a digital balance. For germination studies, fifty seeds per treatment were placed in Petri dishes (15 cm diameter) lined with moistened filter paper. These were maintained at 25 ± 1°C and 75% relative humidity. The germination percentage was recorded after seven days. Seedling vigour was evaluated by measuring the shoot and root lengths of twenty-five seedlings per treatment. The seedling vigour index was computed using the standard formula of Abdul-Baki and Anderson (1973):

Seedling Vigour Index = (Shoot length + Root length in cm) x Germination percentage

Oil content percentage was estimated using Soxhlet extraction apparatus; 30 g of dried, ground seeds per treatment were extracted with n-hexane for 16 hours and the oil content was calculated gravimetrically.

The quantitative data obtained were subjected to analysis of variance (ANOVA) for Randomized Block Design as per the procedure outlined by Gomez and Gomez (1984). The critical difference (CD) values were calculated at a 5% level of significance ($P=0.05$). Significant treatment means were grouped and compared using Duncan's Multiple Range Test (DMRT).

Results and Discussion

The findings of the present investigation clearly demonstrate that different modes of pollination and foliar application of bee attractants significantly influence the quantitative yield and qualitative seed parameters of safflower. The mean performance of safflower under various treatments for yield and quality attributes is summarized in Tables 1 and 2.

Influence of Pollination on Yield and Yield Attributes

The number of capitula per plant did not vary significantly among the treatments (Table 1), ranging from a minimum of 29.11 in pollinator exclusion plots (T_3) to a maximum of 34.15 in plots caged with an *A. mellifera* colony (T_2). Plots sprayed with 50% jaggery solution (T_5), open pollinated plots (T_1) and bee attractant sprayed plots (T_6) recorded 32.87, 32.35 and 31.95 capitula per plant, respectively, which were on par with each other. The non-significant difference indicates that the number of capitula is primarily governed by the genetic potential of the variety and crop management practices rather than pollinator visits. These findings are in complete agreement with Kishanrao (2001) ^[11], who reported non-significant differences in capitula production in safflower across pollination systems, recording 27.43, 26.70 and 25.63 capitula plant⁻¹ under open pollination, managed bee pollination and pollinator exclusion, respectively. Similarly, Dhurve (2008) ^[7] in niger reported that pollinating insects exert a greater influence on seed production parameters than on vegetative yield attributes like capitula per plant.

In contrast, the number of seeds per capitulum was significantly influenced by the pollination treatments. The highest number of seeds per capitulum was recorded in plots caged with *A. mellifera* (33.95), which was significantly superior to all other treatments. Plots sprayed with 50% sugar solution (T_4), bee attractant PARI (T_6) and 50% jaggery solution (T_5) recorded 31.10, 30.05 and 29.53 seeds per capitulum, respectively. These treatments were significantly superior to open pollination (28.10) and water spray control (27.32). The lowest number of seeds per capitulum was recorded in pollinator exclusion plots (24.68) (Table 1). The significant increase in seeds per capitulum in T_2 emphasizes the role of bee visitation in ensuring successful fertilization. Honey bees gather and distribute pollen effectively among the florets. The present results are in line with Kishanrao (2001) ^[11], who reported the highest seeds per capitulum (33.50) in plots provided with managed *A. mellifera* colonies and the lowest (24.01) under pollinator exclusion in safflower. The results are also supported by Rahman *et al.* (2022) ^[25] in sesame and Ranjitha *et al.* (2023) ^[26] in coriander, who observed that honey bee pollination significantly increased seeds per capsule/umbel over other treatments.

Capitulum weight was significantly higher in plots pollinated by

A. mellifera (2.96 g), followed by T_4 (2.77 g), T_6 (2.73 g) and T_5 (2.69 g), which were on par with open-pollinated plots (2.68 g). The minimum capitulum weight was recorded in pollinator exclusion plots (2.09 g), while water sprayed plots recorded 2.59 g. The statistical difference among treatments was significant, with a CD value of 0.25 g. The increased weight in T_2 and attractant sprayed plots is directly attributable to the higher number of seeds set and better seed development resulting from effective pollination. This is corroborated by Prashanth and Belavadi (2009) ^[23] in pigeon pea, who reported significantly higher pod and seed weights under open pollination compared to self-pollinated caged plants. Similar observations were reported by Raghavendra (2018) ^[24] in sunflower, indicating that managed bee pollination improves reproductive success and photosynthetic assimilate partitioning towards developing heads.

The number of filled and unfilled seeds per capitulum also differed significantly among treatments. Plots caged with *A. mellifera* (T_2) recorded the highest number of filled seeds (31.94) and the lowest number of unfilled seeds (2.01). This was followed by sugar solution sprayed plots (27.98 filled and 3.12 unfilled), jaggery solution sprayed plots (26.01 filled and 3.52 unfilled) and bee attractant sprayed plots (25.98 filled and 4.07 unfilled), which were statistically on par with each other. Open-pollinated plots and water sprayed plots recorded 23.84 and 22.89 filled seeds and 4.26 and 4.43 unfilled seeds per capitulum, respectively. The lowest number of filled seeds (17.92) and the highest number of unfilled (6.76) were recorded in pollinator exclusion plots (Table 1). The high proportion of unfilled seeds in pollinator-excluded plots highlights the high level of self-incompatibility or the limitation of mechanical self-pollination in safflower. Bees, through their active foraging, facilitate the cross-transfer and deep deposition of pollen, maximizing the fertilizing capacity of the florets. The present findings are in agreement with Pandey and Aloka (2008) ^[20], who reported that naturally pollinated safflower heads recorded higher filled seeds (47.08) and lower unfilled seeds (7.67) than bagged heads (19.46 filled and 35.30 unfilled). These results are further supported by Öz *et al.* (2009) ^[17] in sunflower and Chaudhary *et al.* (2016) ^[6] in niger.

The seed yield per plant and per hectare differed significantly among the treatments. The highest seed yield per plant (42.56 g) and per hectare (2456.04 kg ha⁻¹) was recorded in plots pollinated by *A. mellifera* (T_2), which was significantly superior to all other treatments. Among the bee attractants, sugar solution spray (T_4) recorded the highest seed yield of 40.02 g per plant and 2256.21 kg ha⁻¹, which was statistically on par with T_2 . Foliar sprays of bee attractant PARI (T_6) and 50% jaggery solution (T_5) also performed well, yielding 2201.96 and 2198.42 kg ha⁻¹, respectively and were superior to open pollination (2163.23 kg ha⁻¹). The lowest seed yield per plant (33.23 g) and per hectare (1995.36 kg ha⁻¹) was recorded under pollinator exclusion (T_3), while water sprayed plots (T_7) recorded 36.57 g plant⁻¹ and 2096.78 kg ha⁻¹. Managed bee pollination resulted in a 13.53 per cent increase in seed yield over open pollination and a 23.08 per cent increase over pollinator exclusion. This yield enhancement is a direct result of cumulative improvement in seeds per capitulum, filled seed numbers and seed setting rates. The findings are in agreement with Kishanrao (2001) ^[11], who reported the highest safflower yield of 2729.70 kg ha⁻¹ in plots provided with managed *A. mellifera* colonies and the lowest in plots without insects (1552.00 kg ha⁻¹). Similar yield increases via bee pollination have been reported in other oilseed crops like mustard (Patidar *et al.*, 2017) ^[21] and niger (Sattigi *et al.*, 2004; Chaudhary *et al.*, 2016) ^[29, 6].

Influence of Pollination on Seed Quality and Physiological Parameters

The thousand-seed weight (test weight) did not differ significantly among the treatments (Table 2), ranging from 45.86 g in pollinator-excluded plots to 48.11 g in plots caged with *A. mellifera*. Similarly, open pollination recorded 46.45 g, sugar spray recorded 47.12 g and jaggery spray recorded 46.95 g. While bee pollination numerically improved the test weight, the lack of statistical significance indicates that seed weight is largely a genetically determined varietal trait controlled by maternal plant capacity rather than pollination intensity. However, the numerical superiority in bee-pollinated plots suggests that efficient fertilization ensures better endosperm development and seed filling. These results align with Kishanrao (2001) ^[11], who observed that thousand-seed weight of safflower was numerically higher under bee pollination but largely conserved. Similar conclusions were drawn by Paiva *et al.* (2003) ^[18] in sunflower, where 100-seed weights were found to be statistically comparable among pollination systems.

Seed setting percentage and seed filling percentage showed significant differences among treatments. The highest seed setting (84.14%) and seed filling (94.18%) percentages were recorded in plots caged with *A. mellifera* (T₂), followed by sugar solution sprayed plots (81.32% and 89.04%), bee attractant PARI sprayed plots (80.66% and 88.39%) and jaggery solution sprayed plots (79.53% and 87.16%). Open pollination (T₁) recorded 77.91% seed setting and 86.70% seed filling, while the lowest values were observed under pollinator exclusion (65.90% and 74.60%). The CD values were 7.16% and 6.24% for seed setting and seed filling, respectively. The high seed setting and filling in T₂ are due to the abundance and frequency of bee visits, ensuring that almost all receptive stigmas received sufficient viable pollen grains. In contrast, self-pollination under caged conditions was inadequate, resulting in a large proportion of empty or partially filled seeds. The present findings confirm the results of Pandey and Aloka (2008) ^[20] in safflower, who reported 85.99 per cent seed set in open-pollinated capitula and only 35.54 per cent in bagged capitula. These results are also supported by Chaudhary *et al.* (2016) ^[6] in niger and Patil and Pastagia (2016) ^[22] in sesame.

Seed germination percentage did not vary significantly among the treatments (Table 2), ranging from 85.50% in pollinator exclusion plots (T₃) to 93.40% in *A. mellifera* pollinated plots (T₂). Other treatments such as sugar spray (T₄) and open pollination (T₁) recorded 90.56% and 89.23% germination, respectively.

Although bee pollination numerically improved germination, the non-significant variation suggests that seed viability is maintained at a high level across treatments, provided the seeds develop to maturity. These findings are in complete agreement with Paiva *et al.* (2003) ^[18] in sunflower, who concluded that pollination systems have a greater impact on overall seed production than on the germination capacity of the seeds. Similar observations were made by Nagpal *et al.* (2017) ^[16] in Indian mustard.

Seedling vigour and seedling vigour index, however, showed highly significant differences among treatments. The highest seedling vigour (11.26) and seedling vigour index (1054.51) were recorded in plots caged with *A. mellifera* (T₂), which was significantly superior to all other treatments. Among the attractants, sugar solution spray (T₄) recorded the next highest seedling vigour (10.24) and vigour index (932.63), followed by jaggery spray (9.74 and 853.94) and bee attractant PARI (10.10 and 797.26). Open pollination (T₁) recorded a vigour index of 795.92, while the lowest seedling vigour (5.84) and seedling vigour index (500.29) were recorded under pollinator exclusion (T₃). The CD values were 0.87 and 164.44 for seedling vigour and vigour index, respectively. The superior vigour of seedlings from T₂ suggests that bee-mediated cross-pollination results in seeds with higher embryo quality and food reserves, which support rapid and healthy seedling growth. These results are in close agreement with Alekya *et al.* (2025a) ^[2] in sesame, who reported significantly higher seedling vigour in managed bee pollination plots compared to pollinator-excluded plots. Similar findings were reported by Nagpal (2016) ^[15] in mustard and Rao *et al.* (2022) in sesame.

Oil content percentage did not differ significantly among the treatments (Table 2), ranging from 22.07% in T₃ to 26.65% in T₂. Open-pollinated plots recorded 24.87% oil, while sugar solution and jaggery solution sprayed plots recorded 24.67% and 23.76% oil, respectively. Although numerically superior in bee-pollinated plots, the differences did not reach statistical significance (CD = 2.98%), indicating that seed oil percentage is primarily a genetic characteristic of the variety. Nonetheless, managed bee pollination significantly enhances total oil yield per unit area by increasing seed yields. The present results are in line with Kishanrao (2001) ^[11] in safflower and Raghavendra (2018) ^[24] in sunflower, who reported that oil content was non-significantly influenced by pollination systems, concluding that honey bee pollination primarily maximizes total seed productivity.

Table 1: Effect of different treatments on yield parameters of safflower during rabi, 2025-2026

Sl. No.	Treatment	Capitula plant ⁻¹	Seeds Capitulum ⁻¹	Capitulum weight (g)	Filled Seeds	Unfilled Seeds	Seed yield /plant	Seed Yield Kg/ ha
T ₁	Open pollination	32.35 ^{ab}	28.10 ^{bc}	2.68 ^{ab}	23.84 ^{bc}	4.26 ^b	37.15 ^{bc}	2163.23 ^{bc}
T ₂	Bee pollination	34.15 ^a	33.95 ^a	2.96 ^a	31.94 ^a	2.01 ^c	42.56 ^a	2456.04 ^a
T ₃	Pollinator exclusion	29.11 ^b	24.68 ^d	2.09 ^c	17.92 ^d	6.76 ^a	33.23 ^c	1995.36 ^c
T ₄	Sugar solution (50%)	31.26 ^{ab}	31.10 ^b	2.77 ^b	27.98 ^b	3.12 ^c	40.02 ^{ab}	2256.21 ^{ab}
T ₅	Jaggery solution (50%)	32.87 ^{ab}	29.53 ^{bc}	2.69 ^{ab}	26.01 ^{bc}	3.52 ^{bc}	38.44 ^{ab}	2198.42 ^{bc}
T ₆	Bee attractant spray	31.95 ^{ab}	30.05 ^{bc}	2.73 ^{bc}	25.98 ^{bc}	4.07 ^b	39.28 ^{ab}	2201.96 ^{bc}
T ₇	Water spray	30.63 ^{ab}	27.32 ^{cd}	2.59 ^{cd}	22.89 ^{cd}	4.43 ^b	36.57 ^{bc}	2096.78 ^{bc}
	SEm ±	1.46	0.90	0.10	1.01	0.14	1.39	71.20
	CD (P=0.05)	4.51	2.79	0.25	3.10	0.42	4.29	219.39
	CV (%)	8.47	5.36	5.37	6.91	5.92	6.31	5.61

Mean followed by the same letters in each column are not significantly different at P=0.05 (DMRT).

Table 2: Effect of different treatments on quality parameters and oil content of safflower during *rabi*, 2025-2026

Sl. No.	Treatment	Test weight (g)	Percentage of seed setting	Seed filling (%)	Seed Germination (%)	Seedling Vigour	Seedling Vigour Index	Oil Content (%)
T ₁	Open pollination	46.45 ^a	77.91 ^{ab}	86.70 ^b	89.23 ^a	8.98 ^{bc}	795.92 ^{bc}	24.87 ^a
T ₂	Bee pollination	48.11 ^a	84.14 ^a	94.18 ^a	93.40 ^a	11.26 ^a	1054.51 ^a	26.65 ^a
T ₃	Pollinator exclusion	45.86 ^a	65.90 ^c	74.60 ^c	85.50 ^a	5.84 ^d	500.29 ^d	22.07 ^a
T ₄	Sugar solution (50%)	47.12 ^a	81.32 ^{ab}	89.04 ^{ab}	90.56 ^a	10.24 ^{ab}	932.63 ^{ab}	24.67 ^a
T ₅	Jaggery solution (50%)	46.95 ^a	79.53 ^{ab}	87.16 ^b	87.63 ^a	9.74 ^{bc}	853.94 ^{bc}	23.76 ^a
T ₆	Bee attractant spray	46.56 ^a	80.66 ^{ab}	88.39 ^{ab}	86.46 ^a	10.10 ^{bc}	797.26 ^{bc}	23.43 ^a
T ₇	Water spray (Control)	46.13 ^a	75.52 ^b	85.45 ^b	88.45 ^a	8.32 ^c	691.41 ^c	23.18 ^a
	SEm ±	1.49	2.32	2.02	2.89	0.28	53.36	0.97
	CD (P=0.05)	4.58	7.16	6.24	8.92	0.87	164.44	2.98
	CV (%)	5.51	5.17	4.05	5.65	5.30	11.50	6.97

Mean followed by the same letters in each column are not significantly different at P=0.05 (DMRT).

Conclusion

The present investigation underscores the critical role of honey bees and managed pollination systems in enhancing the yield and seed quality of safflower. Introducing managed *Apis mellifera* colonies into safflower fields significantly improved key yield attributes, such as seeds per capitulum, capitulum weight and filled seeds, leading to a 13.53 per cent increase in seed yield per hectare over open pollination and a 23.08 per cent increase over pollinator exclusion. Additionally, bee-mediated pollination improved physiological seed quality, producing seedlings with significantly higher vigour and vigour indices. Foliar application of bee attractants, particularly a 50% sugar solution sprayed at 25 per cent flowering, also proved highly effective in boosting yields. Although parameters such as capitula per plant, test weight, seed germination and oil percentage were found to be primarily controlled by genetics, managed pollination numerically enhanced them. Therefore, integrating managed honey bee hives (*A. mellifera*) and utilizing sugar solution sprays are highly recommended for safflower growers to maximize crop productivity, ensure seed quality and enhance economic returns in dryland and irrigated farming systems.

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