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RESEARCH ARTICLE

Enhancing pollination efficiency in onion (*Allium cepa* L.) using indigenous bee attractants

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Abstract

A two-year field experiment (2023-24 and 2024-25) was conducted to evaluate the efficacy of indigenous bee attractants-such as coconut water, pomegranate (*Punica granatum* L.) juice and dates (*Phoenix dactylifera* L.) extract on the foraging activity of honeybee (*Apis mellifera* L.) and the stingless bee (*Tetragonula iridipennis*) in onion (*Allium cepa* L.). Attractants were applied at critical flowering stages and bee visitation rates were recorded at different intervals after application. Both pomegranate juice and dates extract at 10 % concentration significantly increased visitation rates of *A. mellifera* and *T. iridipennis* compared to coconut water, with peak activity occurring on the 3rd and 5th days following the second spray. The results revealed that fruit-based attractants are more effective in enhancing mean bee visitation rates, improving foraging consistency and producing statistically significant differences ($p < 0.05$). Enhanced pollinator activity was associated with improved pollination efficiency, supporting the likelihood of yield gains. The findings highlight the feasibility of incorporating locally available, eco-friendly attractants into onion seed production systems to sustainably increase pollinator-mediated productivity. Adoption of such natural attractants could serve as a low-cost, eco-friendly strategy to address pollination gaps and enhance seed yield in short-day onion cultivars.

Keywords: *Apis mellifera*; coconut water; dates extract; pomegranate juice; *Tetragonula iridipennis*

Introduction

Bee pollination is essential for optimizing seed production in onion (*Allium cepa* L.), an economically important vegetable crop (1). Onion flowers rely heavily on insect-mediated cross-pollination, with honeybees (*Apis mellifera*) and stingless bees acting as key agents, facilitating successful pollen transfer and hence improving seed set and quality (2). Therefore, enhancing the foraging activity of these pollinators during entire flowering stages is critical for improving seed yield and quality in onion (3).

The use of indigenous bee attractive extracts like pomegranate juice, dates extract and coconut water has emerged as environmentally sustainable and economically viable ways to enhance the pollinator visitation in agroecosystems (4). The natural sugars alongside volatile organic compounds present in these extracts function as potent olfactory and gustatory stimulants, thereby encouraging bees to forage more (5). Notably, pomegranate juice and date extract typically contain higher sugar content and a more complex aromatic profile than coconut water, which is relatively low in both sugar concentration and volatile attractants; this disparity likely explains their differing efficacy in enhancing bee activity (6).

Studies on onion seed production systems have shown that applying these indigenous attractants at critical phonological stages, specifically at 15 % and 50 % flowering, significantly increases bee visitation frequency and density per unit area and time. This enhanced bee activity optimizes pollination efficiency (7). Importantly, increased pollinator activity directly correlates with increased pollen transfer, resulting in better seed set, quality and yield (8).

Moreover, the use of locally available, plant-based attractants like pomegranate juice and dates extract aligns seamlessly with principles of sustainable agriculture by reducing reliance on synthetic attractants that are costly, less accessible and may pose environmental concerns (9). A timely application of indigenous bee attractants aligned with precise floral phenology ensures pollinator stimulation during peak floral receptivity. This enhances pollination success and proves promising for integrated pollination management in onion seed production (10). The judicious use of these attractants can enhance the foraging activity of key pollinators such as *A. mellifera*, thereby fostering sustainable improvements in seed yield and quality (9, 10).

This study has been conducted to evaluate the impact of natural bee attractants like pomegranate juice, dates extract and coconut water on the visitation frequency and activity of *A. mellifera* and *T. irridipennis* during onion flowering. The research aims to quantify how these extracts enhance bee foraging behavior at critical flowering stages, thereby improving pollination efficiency and seed yield in onion. This study provides valuable insight into the effectiveness of environmentally sustainable attractants in stimulating honeybee activity for optimizing onion seed production.

Materials and Methods

Experimental site and crop details

The experiment was conducted during the *Rabi* season of 2023–25 at the experimental farm of the ICAR-Directorate of Onion and Garlic Research (DOGR), Rajgurunagar, Pune, Maharashtra. The site is situated at an altitude of 612 meters above mean sea level, with geographical coordinates of latitude 18.9112° N and longitude 73.8798° E. The region is characterized by a tropical semi-arid climate with moderate winter temperatures and abundant sunshine, providing favourable conditions for flowering and pollinator activity.

The study was conducted with the onion variety 'Bhima Shakti', which is known for its high seed yield potential and synchronous flowering (11). The crop was raised following standard agronomic practices included land preparation with proper ploughing, application of recommended doses of fertilizers, timely irrigation, manual weeding and regular pest and disease monitoring. Planting was carried out at appropriate spacing and nutrient levels as recommended by ICAR-DOGR. Irrigation and pest management were maintained uniformly across all treatments.

Experimental design and treatments

The experiment was set up in a randomized block design (RBD) with three replications, where each plot measured 5 m × 5 m and contained a uniform number of onion umbels at similar flowering stages. To ensure consistent sampling, the number of umbels observed per plot was standardized using a quadrat method covering a 1 m^2 area and the total sample size was derived from the sum of all observed umbels across the three replicates. Buffer rows were maintained between plots to prevent treatment drift. At the onset of flowering, one healthy hive of *A. mellifera* and one of *T. iridipennis* were placed at the center of each plot and allowed to forage freely.

Attractants were applied directly to umbels with a hand-operated sprayer twice during the seed production cycle: once at 15 % flowering and again at 50 % of the peak flowering period (50 %-80 % flowering). Sprays were administrated during the early morning hr (07:00 hr-08:00 hr). Control plots did not receive any spray application. Data from the two years of experimentation were analyzed separately and then pooled for combined interpretation.

The indigenous bee attractants used in this study consisted of four treatments: pomegranate juice at 10 % concentration (T_1), dates extract at 10 % concentration (T_2), coconut water at 10 % concentration (T_3) and an unsprayed control (T_4).

Pomegranate juice

All treatments were evaluated under field conditions. Extract concentrations were freshly prepared on the day of application using clean, food-grade raw materials and distilled water. To avoid microbial contamination, all containers, blenders and filters were sterilized with 70 % ethanol prior to use. Each natural extract was diluted to 10 % (v/v) with distilled water and no chemical additives or preservatives were added.

Dates extract

Seedless dates (100 g) were soaked in 500 mL warm distilled water for 4 hr-6 hr to soften. The softened dates were blended into a smooth paste and then diluted with distilled water to a total volume of 1 L. The mixture was filtered through muslin cloth to obtain a clear extract and the final concentration was adjusted to 10 % (w/v), corresponding to 100 g date pulp per liter. The extract was used immediately or within the same day.

Coconut water

Fresh coconut water was collected from tender green coconuts and filtered through fine mesh or muslin cloth. A 10 % dilution was prepared by mixing 100 mL coconut water with 900 mL distilled water. It was stored in shaded, ambient temperature conditions to maintain stability and prevent degradation, helping to avoid fermentation and preserve the solution's efficacy for optimal bee attraction during spraying.

Pollinator visitation observations

Bee visits were visually recorded between 12:00 hr and 14:00 hr following the method (12). Data were collected from five randomly selected umbels per plot. The number of insect visits per umbel was counted over a 5 min interval (13). Observations focused exclusively on two commonly occurring bee species identified as primary pollinators such as *A. mellifera* and *T. iridipennis*.

Statistical Analysis

Data on pollinator visitation and foraging behavior were subjected to analysis of variance (ANOVA) using a RBD. Treatment means were compared by Duncan's multiple range test (DMRT) at 5 % level of significance. All statistical analyses and data visualization were performed using the software KAU GRAPES (General R-based Analysis Platform for Experimental Statistics) (14).

Results and Discussion

Effect of different bee attractants on the foraging activity of *Apis mellifera*

The forage visitation rate of *A. mellifera* on different bee attractants sprayed onion plots were presented in the Table 1. The results revealed that, all attractant treatments were effective and significantly increased the visitation rate of *A. mellifera* and *T. iridipennis*. In 2023-24, pomegranate juice recorded the highest mean peak visitation (14.82 bees/m^2/min on the 3rd day after the second spray), followed by dates extract (13.88 bees/m^2/min) and coconut water (12.96 bees/m^2/min). A similar trend was observed in the second year (2024-25), with visitation rate of 15.56, 14.57 and 13.71 bees/m^2/min for pomegranate juice, date extracts and coconut water, respectively. Visitation constantly peaked on the 3rd or 5th day after the second spray and decreased by day 7 (Table 1).

Treatments based on pomegranate juice and dates extract were statistically superior to coconut water (CD at 5 % ranged from 1.65 to 3.47) and also resulted in lower coefficients of variation (CV ranging from 8.1 % to 15.87 %), indicating more consistent and reliable enhancement of *A. mellifera* activity. The increased attractiveness of fruit-based solutions is likely owing to their higher sugar (sucrose/fructose) content and a rich aromatic volatile profile, which stimulate bee foraging through both olfactory and gustatory cues (15). This is consistent with prior research indicating that bees are more strongly attracted to high-sugar, aromatic solutions such as jiggery or fruit juice sprays (16).

These findings are in agreement with earlier reports that natural fruit-based attractants, rich in sugars, organic acids and volatiles, stimulate honeybee foraging responses (17, 18). Enhanced bee activity has previously been shown to correlate with improved pollination efficiency in cross-pollinated crops such as onion (19, 20). Similar observations were reported earlier, who found that

Table 1. Effect of bee attractant on activity of *Apis mellifera* in onion

Year of Planting	Treatment	Mean number of *Apis mellifera* bees/m²/day (based on six 5-min observations)										GM	SE (m) ±	CD (5 %)	CV (%)
		1st spray at 15 % per flowering					2nd spray at 50 % per flowering								
		DBFS	1ST	3RD	5TH	7TH	DBSS	1ST	3RD	5TH	7TH				
2023-24	Coconut water 10 %	6.33 (2.61)	9.3 (3.13)^{c}	11 (3.39)^{c}	10.01 (3.24)^{d}	10.07 (3.25)^{0}	10.98 (3.39)	12.96 (3.67)^{c}	13.06 (3.68)^{d}	12.3 (2.61)^{d}	11.4 (3.13)^{d}	10.74	0.86	2.56	13.91
	Pomegranate juice 10 %	6 (2.55)	10.93 (3.38)^{bc}	13.18 (3.70)^{bc}	12.07 (3.55)^{bc}	11.8 (3.51)^{cd}	12.1 (3.55)	14.1 (3.82)^{bc}	14.82 (3.91)^{bc}	13.36 (2.55)^{bc}	12.6 (3.38)^{bc}	12.06	0.57	1.68	8.11
	Dates extract 10 %	6.67 (2.68)	10.91 (3.38)^{bc}	12.88 (3.66)^{bc}	11.61 (3.48)^{cd}	11.07 (3.40)^{cd}	11.98 (3.53)	13.88 (3.79)^{bc}	13.33 (3.72)^{bc}	12.97 (2.68)^{bc}	12.44 (3.38)^{c}	11.81	0.78	2.31	11.41
2024-25	Coconut water 10 %	6.65 (2.74)	9.77 (3.29)^{c}	11.55 (3.56)^{e}	10.51 (3.40)^{c}	10.57 (3.41)^{d}	11.53 (3.56)	13.61 (3.85)^{c}	13.71 (3.86)^{d}	12.92 (2.74)^{c}	11.97 (3.29)^{c}	11.28	0.56	1.65	8.53
	Pomegranate juice 10 %	6.30 (2.68)	11.48 (3.55)^{b}	13.84 (3.89)^{c}	12.67 (3.73)^{b}	12.39 (3.69)^{c}	12.71 (3.73)	14.81 (4.01)^{b}	15.56 (4.11)^{b}	14.03 (2.68)^{b}	13.23 (3.55)^{b}	12.74	1.17	3.47	15.87
	Dates extract 10 %	7.00 (2.81)	11.46 (3.55)^{b}	13.52 (3.84)^{c}	12.19 (3.65)^{b}	11.62 (3.57)^{c}	12.58 (3.71)	14.57 (3.98)^{b}	14.00 (3.91)^{d}	13.62 (2.81)^{c}	13.06 (3.55)^{b}	12.36	1.08	3.20	15.11

DBFS - days before first spray, DBSS - days before second spray. Figures in parenthesis are square root of √ x+0.5. In a column, means followed by same alphabet do not differ significantly (p = 0.05) by DMRT.

attractants significantly increased *A. mellifera* visitation, leading to improved seed set in onion (21).

In addition to the sugar and volatile content that drive bee attraction, environmental factors such as temperature, humidity, wind speed and sunshine play a crucial role in year-to-year variation of bee foraging activity (15). Variability in bee visitation rates between years can be attributed to fluctuations in these environmental conditions, with bee activity increasing at temperatures between 22 °C and 33 °C and during sunnier periods (15, 16). High humidity, rainfall or cloudiness and extreme temperature (either very high or very low) can suppress bee foraging (16). Variable weather can therefore modulate the effectiveness of attractant treatments and result in differential bee visitation and seed set year to year (17). Such variability highlights the need to consider climatic factors when interpreting results and planning pollination management strategies in onion seed production.

Effect of different bee attractants on the foraging activity of *Tetragonula iridipennis*

The forage visitation rate of *T. iridipennis* on different bee attractants sprayed onion plots was presented in the Table 2. The results revealed that, all treatments improved *T. iridipennis* visitation, but the 10 % date extract produced the highest and most consistent activity across both years. In the first year (2023-24), mean peak visitation was 54.0 bees/m²/min for dates extract, 51.8 for pomegranate juice and 50.0 for coconut water. In the second year (2024–25), the visitation rates in these treatments were substantially increased to 63.1, 59.5 and 53.1 bees/m²/min respectively. Peak activity was consistently recorded on the 3rd or 5th day after the second spray.

The increased efficacy of dates extract for enhanced stingless bee activity in onion can be attributed to its higher nutritional and sugar content, along with a more complex volatile profile, which serves as a potent foraging cues for *Tetragonula* species (22). Pomegranate juice offered similar benefits, while coconut water, due to its lower sugar and minimal volatiles, was the least effective-consistent with findings that floral visitors prefer high-calorie rewards.

The present study revealed that attractant have significant effect on both species 3-5 days after application, after which bee visitation decreased, most likely due to sugar consumption, evaporation or microbial decomposition (4). These findings highlight the practical relevance of timing attractant sprays to coincide with mass anthesis and peak floral receptivity to ensure optimal pollination (8). Consistent increases in honey bee and stingless bee visitation illustrate the agronomic value of fruit-based attractants for managed pollination in onion (21). Increased pollinator activity has been linked with better pollen deposition,

Table 2. Effect of bee attractant on activity of *Tetragonula iridipennis* in onion

Year of Planting	Treatment	Mean number of *Tetragonula irridipennis* bees/m²/day (based on six 5-min observations)										GM	SE (m) ±	CD (5 %)	CV (%)
		1st spray at 15 % per flowering					2nd spray at 50 % per flowering								
		DBFS	1ST	3RD	5TH	7TH	DBSS	1ST	3RD	5TH	7TH				
2023-24	Coconut water 10 %	33.3 (5.82)	40.9 (6.66)^{d}	47.0 (6.89)^{d}	47.6 (6.93)^{d}	34.0 (5.88)^{e}	49.7 (7.08)	41.0 (7.18)^{c}	46.0 (7.52)^{c}	48.8 (7.16)^{d}	50.0 (7.11)^{d}	43.83	2.74	8.14	10.82
	Pomegranate juice 10 %	30.8 (5.59)	43.7 (6.79)^{bc}	53.6 (7.36)^{c}	50.9 (7.17)^{cd}	39.9 (6.36)^{de}	52.0 (7.25)	48.8 (7.37)^{bc}	50.1 (7.66)^{bc}	51.7 (7.56)^{b}	51.8 (7.23)^{cd}	47.33	2.43	7.23	8.90
	Dates extract 10 %	32.4 (5.73)	45.0 (6.75)^{bc}	52.3 (7.27)^{d}	50.0 (7.11)^{cd}	50.0 (7.11)^{bc}	51.0 (7.18)	53.3 (7.33)^{ab}	53.7 (7.56)^{bc}	54.0 (7.78)^{b}	52.3 (7.27)^{b}	49.40	3.10	9.20	10.85
2024-25	Coconut water 10 %	35.4 (6.00)	46.3 (6.84)^{b}	50.1 (7.12)^{b}	49.8 (7.09)^{b}	36.2 (6.06)^{c}	52.1 (7.25)	53.0 (7.31)^{b}	58.5 (7.68)^{b}	53.1 (7.32)^{b}	52.3 (7.27)^{ab}	48.68	2.67	7.92	9.49
	Pomegranate juice 10 %	32.0 (5.70)	48.1 (6.97)^{b}	57.2 (7.60)^{b}	53.5 (7.34)^{b}	42.4 (6.55)^{bc}	54.3 (7.40)	56.1 (7.52)^{b}	62.0 (7.90)^{b}	59.5 (7.75)^{ab}	54.2 (7.40)^{ab}	51.93	3.59	10.66	11.97
	Dates extract 10 %	33.7 (5.85)	47.0 (6.89)^{b}	56.9 (7.58)^{b}	52.8 (7.30)^{b}	53.1 (7.32)^{ab}	53.2 (7.33)	55.5 (7.48)^{b}	59.8 (7.77)^{b}	63.1 (7.98)^{ab}	54.9 (7.44)^{ab}	53.00	4.05	12.03	13.23

DBFS - days before first spray, DBSS - days before second spray. Figures in parenthesis are square root of √ x+0.5. In a column, means followed by same alphabet do not differ significantly (p = 0.05) by DMRT.

higher seed set, yield and quality in bee-pollinated crops. Studies suggest that adding 2-4 bees/m^2/min during bloom can boost onion seed yield by 15 %-25 %.

In the current study, although these indigenous attractants demonstrated significant impact on bees foraging activity but transient effect that varied with the weather, competing floral resources and possibly annual fluctuation in bee populations. More studies with different crops, ecotypes and seasons are needed to provide robust recommendations.

Conclusion

The findings from both seasons demonstrate that 10 % dates extract and 10 % pomegranate juice are highly effective in promoting the foraging activity of key pollinators such as *A. mellifera* and *T. iridipennis* in onion seed crops, significantly outperforming 10 % coconut water. Their timely application, particularly at critical flowering stages such as 15 % and 50 % anthesis, ensures sustained pollinator visitation, enhancing pollination efficiency and potentially increasing seed yield and quality. Therefore, it is recommended that onion seed producers integrate these indigenous fruit-based attractants into their pollination management programs to achieve sustainable production benefits. Farmers should apply attractants early in the morning during peak flowering periods and repeat the application to maintain high pollinator activity. Moreover, considering environmental factors such as temperature and weather conditions can help optimize the timing and frequency of attractant sprays for maximal effect. Adoption of these cost-effective, eco-friendly attractants can reduce reliance on synthetic chemicals, supporting both crop productivity and environmental sustainability in onion seed production systems.

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Authors' contributions

PTR contributed to the conceptualization of the study, data curation, formal analysis, investigation, methodology development, statistical analysis and preparation of the original draft, as well as writing, reviewing and editing the manuscript. VK and DSA were involved in data curation, formal analysis, investigation, methodology, statistical analysis and writing through review and editing.

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