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Performance of Fruit Juice as a Nectar Substitute for Sustaining the Indian Honey Bee Colonies During Dearth Period

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Abstract

Honey bees (*Apis cerana indica*) are important for pollination and agricultural productivity, but a lack of nectar and pollen resources during the dearth period will negatively impact their survival and colony performance. The present study was carried out at the apiary of PAJANCOA&RI, Karaikal, during summer and winter 2022 to assess the efficacy of various fruit juices as artificial nectar substitutes for conventional sugar syrup. A total of 24 colonies were exposed to 8 treatments in 3 replications under a randomized block design. Parameters like diet consumption rate, worker bee population, colony biology, foraging activity, pollen and nectar storage, and correlations with weather variables. The findings indicated that the treatments differed significantly ($p < 0.05$). Pumpkin juice nectar substitute (T6) always showed the highest intake (490 ± 5.5 ml), highest pollen cell storage (220 ± 1.3), superior brood production (eggs: 283 ± 4.3, larvae: 304 ± 6.2, pupae: 305 ± 2.2), and higher worker bees (180 ± 3.4). Maximum honey cells (357 ± 3.2) were favored by sugar syrup (T7), but T6 encouraged the highest foraging activity during both morning and evening observations. According to correlation analysis, foraging during summer was positively influenced by relative humidity and sunshine hours, and wind velocity had a strong positive effect during winter. The results imply that artificial nectar supplements, especially pumpkin juice, not only sustain colony growth and honey productivity during floral scarcity but also increase the foraging efficiency. These findings offer practical knowledge for beekeepers in nectar-poor areas to improve colony resilience and maximize honey production.

Introduction

As eusocial insects from the *Apis* genus, honey bees are essential pollinators of flowering plants. Their unique foraging habits and specialized body parts for collecting floral rewards make them exceptionally efficient. In fact, honey bees contribute to 85% of the pollination required to sustain a third of the world's food supply. According to Sharma et al. (2022), India's vast vegetation, which makes up 7% of the global total, could support 200 million bee colonies, creating direct employment for over 21.5 million people. Honeybees play an important role as pollinators, collecting nectar and pollen to produce honey and pollinating crops to increase yields. A bee shortage would impair the collection of these key resources (Jovanovic et al., 2021). Furthermore, habitat loss, predators, parasites, diseases, pesticide exposure, and climate change all negatively impact bee populations within colonies (Mull et al., 2022). Honeybee feeding patterns are critical for sustaining populations and ensuring colony growth during periods of food shortage (Russell et al., 2013; Colin et al., 2022). Furthermore, the growth and development of the beehive colony depend on an adequate food supply (Harris, 2023).

Honey bees can visit multiple food sources at the same time and travel long distances to acquire major food resources like nectar and pollen, which they store in their colonies as honey and beebread (Wright et al., 2018). Among these, nectar is the primary source of carbohydrates required to meet energy demands (Abou-Shaara, 2014; Khan et al., 2021). Pollen provides honey bees with macro and micronutrients such as proteins, minerals, vitamins, and lipids, which are required for brood rearing, maturation, adult longevity, and overall colony development (Arien et al., 2018).

The efficacy of beekeeping is determined by the abundance of bee-friendly flora in the vicinity of the apiary, taking into account varying climatic conditions. The availability or ease of access to bee-friendly flora varies throughout seasons in certain places. The dearth season is the time of year when there isn't enough flora to attract bees (Doke et al., 2015; Shitaneh et al., 2022). The limited availability of bee flora and inadequate food stocks within honeybee colonies negatively affect brood rearing, honey production, and colony growth and development (Shitaneh et al., 2022). Honeybees obtain nutrition from nectar and pollen, and honey is created by the bee's enzymatic conversion of nectar (Paray et al., 2021). However, maintaining honeybee colonies is a substantial challenge due to a lack of natural flora, nectar, and pollen during the dearth period (May-October) (Doke et al., 2015). Various diseases and pest populations were also prevalent during the period. To strengthen and increase the productivity of the bee colony, a healthy feeding plan should be implemented. As a result, they require food supplements during the dearth period, and it is critical to give honeybee colonies with pollen substitutes or nectar supplements during times of dearth to ensure future honey production (Khan & Ghramh, 2022; Khan et al., 2023).

The nutritional value of supplementary foods is critical for honeybee health and growth (El Ghouizi et al., 2023). According to researchers, honeybees can consume complex carbohydrates, which are essential for their role as food processors in honeybee colonies (Hrassnigg & Crailsheim, 2005). According to feeding tests on various carbohydrates, sucrose (two parts sugar and one part water) is the best carbohydrate supplement for honeybees. In spring, honeybee colonies fed with various stimulating diets showed a 6% increase in brood population. Using sugar syrup, pollen supplement, or a combination of the two is beneficial during seasons of scarcity for producing larger foragers, thereby increasing honey supply (Paray et al., 2021).

However, overfeeding with sugar syrup can negatively affect both the quality and composition of honey (Siddiqui et al., 2017). Bees may transform undigested sugar syrup into a sugar-based product, affecting the overall quality of honey in the colony (Guler et al., 2007; Kamal et al., 2019). Research has shown that different sugar sources alter the growth and development of honey bees (Kaftanoglu et al., 2011). Honey has been shown to increase the activity of digestive enzymes in the midgut of overwintering bees and promote the development of midgut tissues. Furthermore, sucrose syrup and high fructose syrup have been demonstrated to increase the expression of antioxidant genes in the midgut of overwintering bees (Liu et al., 2017). Sugar syrups lack the complex nutritional profile found in natural nectar, which includes essential amino acids, vitamins, minerals, and antioxidants (Tlak Gajger et al., 2025). This has led to a growing interest in developing more nutritious and biologically complete artificial diets. One promising avenue is using fruit juices as a carbohydrate-rich supplement. Fruit juices offer a more complex array of sugars (fructose, glucose, and sucrose) and micronutrients than simple sugar syrup. They also contribute vitamins, minerals, and phytochemicals to honey bees that contribute to the overall health and resilience of bee colonies. Also, this approach offers a sustainable way to utilize agricultural byproducts or surplus fruits.

The Karaikal U.T of Puducherry study area has extreme climatic conditions, such as severe summer and rainy seasons. During summer, the temperature reaches around 40 °C with 70% relative humidity, whereas about 1200 mm of annual rainfall is received from June to October. It is very difficult to maintain bee colonies during dearth periods without supplementing with artificial food. This study was conducted to evaluate the efficacy of artificial nectar supplements, such as fruit juices, as a viable alternative to conventional sugar syrup for supplementing honey bee colonies. In addition, it aimed to examine the effect of artificial nectar supplementation on various parameters of honey bee colonies, including diet consumption rate, honey bee biology, and foraging activity. The findings of this study may provide valuable guidelines for beekeepers in the Karaikal region on managing colonies more effectively and adopting innovative practices to address food scarcity during periods of nectar shortage.

Materials and methods

Experimental site and design

The present study was carried out at the apiary in the Western farm of PAJANCOA&RI, Karaikal, Puducherry. Location is at 10°55'N latitude and 79°49'E longitude, at an altitude of 4 meters above mean sea level (MSL). About 24 Indian honey bee colonies were used in the present experiment to study their performance against different artificial nectar substitutes. Each honey bee colony had six brood frames with full strength of egg, larva, pupae, and adults. The experiment was conducted during the summer and winter of 2022. The first season started from 18 to 29 Standard Meteorological Week (SMW) (March to July), and the second season started from 32 to 43 SMW (July to November). In this experiment, eight treatments, replicated three times, were maintained, with water as the control treatment, and the experimental design was a randomized block design (RBD). The treatments were imposed once a week. The experiment was conducted on the honeybee species *Apis cerana indica.*

Preparation of artificial nectar substitutes and feeding

The following fruit juices, each 500 ml, were placed in plastic cups for each bee colony in the early morning (8.00 am) at weekly intervals (Standifer et al., 1977).

Table 1. Preparation of artificial nectar substitutes.

Treatment No	Treatments	Quantity of rawmaterials needed 24 (kg/ ml/ mg/ no)	Fruit juices extracted (500 ml per colony)
T1	Kamala orange juice + turmeric powder + health	Kamala orange - 5 fruits Turmeric powder - 2 gm Health ok syrup - 5 ml	Kamala orange juice - 250 ml Water - 250 ml Total extract - 500 ml
T2	Papaya fruit juice + sugar + turmeric powder + health	Papaya fruit - 1 kg Sugar - 100 gm Turmeric powder - 2 gm Health ok syrup - 5 ml	Papaya fruit juice - 400 ml Sugar solution - 100 ml Total extract - 500 ml
T3	Ocimum leaf juice + Sugar solution + turmeric powder + pepper powder + lemon juice	Sugar - 450 gm Turmeric powder - 2 gm Pepper powder - 2 gm Ocimum leaf - 50 no. Lemon fruit - 2 no.	Sugar - 450 gm Water - 450 ml Sugar solution - 450 ml (1:1) Ocimum leaf juice - 30 ml Lemon juice - 20 ml Total extract - 500 ml
T4	Moringa leaf juice +sugar +t urmeric powder + vitaminE	Moringa leaf - 500 gm Sugar - 250 gm Turmeric powder - 2 gm Vitamin E capsule - 1 no.	Moringa leaf juice - 250 ml Sugar solution - 250 ml Total extract - 500 ml
T5	Paneer grapejuice+ turmericpowder + vitaminE + sugar	Paneer grape - 500 kg Turmeric powder - 2 gm Vitamin E capsule - 1 no. Sugar - 200 gm	Paneer grape juice - 300 ml Sugar solution - 200 ml Total extract - 500 ml
T6	Pumpkin fruit juice + sugar +turmeric powder+vitamin E	Pumpkin fruit - 1 kg Sugar - 100 gm Turmeric powder - 2 gm Vitamin E capsule - 1no.	Pumpkin fruit juice - 400 ml Sugar solution - 100 ml Total extract - 500 ml
T7	Sugar syrup at 1 :1	Sugar - 500 kg Water - 500 ml	Sugar solution (1:1) ratio Total extrac t- 500 ml
T8	Untreated check (Water)	Water - 500 ml	Water - 500 ml

Data collection

Consumption rate of artificial nectar substitutes

About 500 ml of artificial food substitute was given to each bee colony at 8.00 AM every SMW, and on the same day evening, the remaining quantity of fruit juice was measured with the help of a measuring cylinder. The initial volume and leftover volume of fruit juices were calculated and recorded every week. The artificial food substitute was placed at weekly intervals during summer and winter 2022 (Kencharaddi et al., 2003).

Bee Biology

On the second day after administering artificial nectar substitutes to each honey bee colony, bee biology parameters, such as the numbers of eggs, larvae, and pupae, were recorded using the 10 x 10 cm^2 quadrat method. All six brood frames were removed from the hive, and the 10 x 10 cm^2 quadrats on both sides of the frames were placed and counted by slowly moving the adult bees for each treatment replication at weekly intervals, and then the mean was calculated (**Fig 1**).

Population of Worker bee

The total number of worker bees per 10 x 10 cm^2 on a comb was measured with a quadrat for each replication across all treatments at weekly intervals, and the mean was recorded.

Pollen and Nectar

The total area covered and sealed by nectar and pollen cells per 10 x 10 cm^2 quadrat for each replication from all treatments at weekly intervals was recorded, and the mean was calculated.

Foraging activity

Foraging activities were determined in terms of the number of worker bees going out, coming in with pollen loads (pollen foragers), and without pollen loads (nectar foragers). Weekly observations were recorded for 5 minutes at 2 times: 6.00 AM and 4.00 PM (Reddy et al., 2015).

Fig 1. Measurements of different parameters using 10 × 10 cm² quadrat.

Correlation between weather parameters and foraging activity

Influence of weather parameters such as maximum and minimum temperature (°C), relative humidity (RH) (%), rainfall (mm), wind velocity (kmph), and sunshine hours were recorded from the observatory located at the PAJANCOA&RI. The weekly data on the pollen foragers, nectar foragers, and outgoing bees for foraging activities were correlated with the weather data during the study period. The contribution of climatic factors to variability was assessed using correlation analyses (Nishanthini & Kanagarajan, 2024).

Statistical analysis

The total amount of nectar substitute consumed, bee biology, honey bee population, pollen and nectar area, and foraging activity were compared across the treatments. Statistical analysis of various treatments was conducted using the 'R' Studio (Team, R.D.C, 2019). Analysis of variance (ANOVA) tests were used to detect significant differences (at a significance level of a = 0.05) within treatments. The means were compared using the least significant difference (LSD) test at a significance threshold of 5%. Furthermore, the Tukey post hoc test was performed to make multiple comparisons between groups at the 0.05 level. Pearson correlation was performed between weather parameter and foraging activity.

Results

Consumption rate of artificial nectar substitutes

Consumption of artificial nectar substitutes by honey bees varied significantly across the treatments during the experimental period in summer and winter 2022. The boxplot shows that the highest consumption was recorded in T6 (490 ± 5.5 ml), followed by T7, and the lowest in T1. One-way ANOVA with Tukey's test confirmed the significance ($p < 0.05$) among the treatments (**Fig 2A**). The line graph demonstrates the monthly trend of juice consumption pooled by treatments. Across months, T6 consistently maintained the highest consumption, peaking in August at nearly 500 ml before slightly declining towards October. T7 showed a similar trend, but with lower values than T6 (**Fig 2B**).

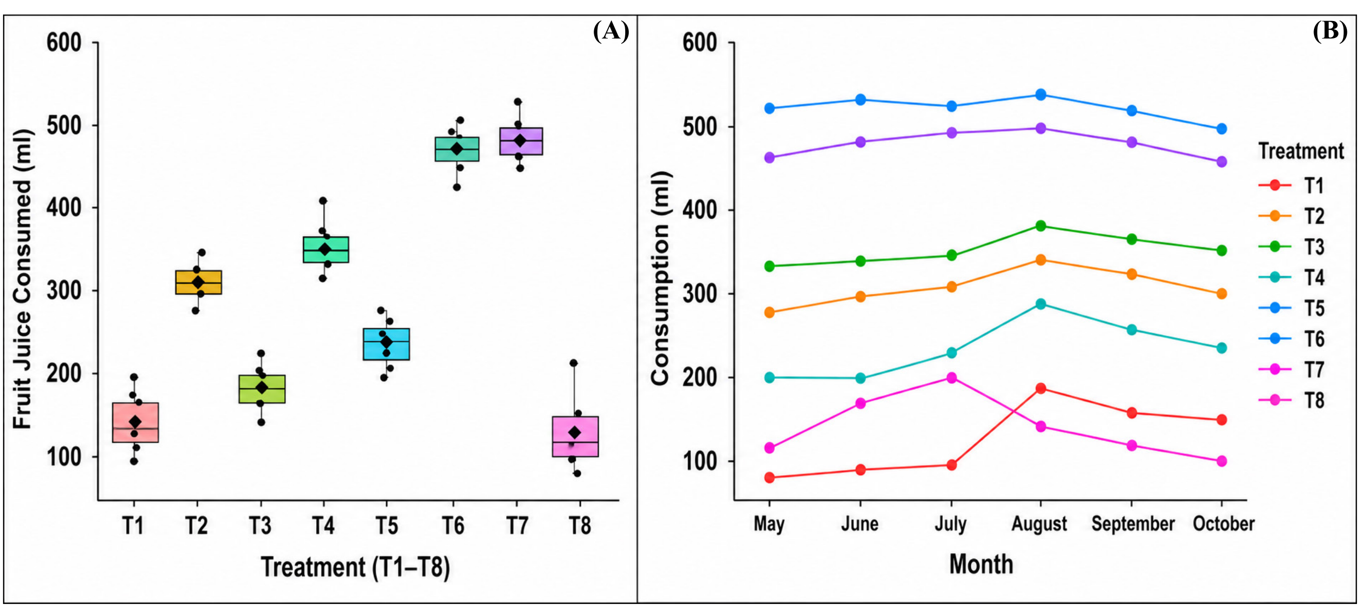

Fig 2. Mean milliliter (ml) of artificial nectar supplements consumed by honey bee colonies in each treatment. (A) The box plot shows the maximum milliliters (ml) (mean ± standard error) of artificial nectar supplement consumption by honeybee colonies over the time of observation. (B) The line graph shows the maximum mean milliliters (ml) of various artificial nectar supplements consumed by the honey bee colony per month during summer and winter 2022.

Bee Biology

Significant differences ($p < 0.05$) were observed among the treatments (T1 to T8) for egg, larval, and pupal population of honey bees (**Fig 3**). For eggs, the highest population was recorded in T6 (283 ± 4.3 no. of eggs), which was statistically similar to T4 and T3, but significantly higher than T1, T2, T5, T7 and T8. T1 and T2 show intermediate values, while T7 and T8 had the lowest egg populations. For larvae, T6 (304 ± 6.2 no. of larvae) again showed the highest population, statistically on par with T4, but significantly greater than all other treatments. The lowest larval population was recorded in T8. For pupae, the trend was similar to that of the egg and larvae. T6 (305 ± 2.2 no. of pupae) showed the best treatment for bee biology.

Population of Worker bee

The adult bee population differed significantly ($p<0.05$) across treatments when data from summer and winter 2022 were analyzed (**Fig 4**). The highest population was recorded in treatment T6, with a mean of 180 ± 3.4 adult bees, which was significantly higher than all other treatments, followed by T4. The minimum adult bee population was observed in T8.

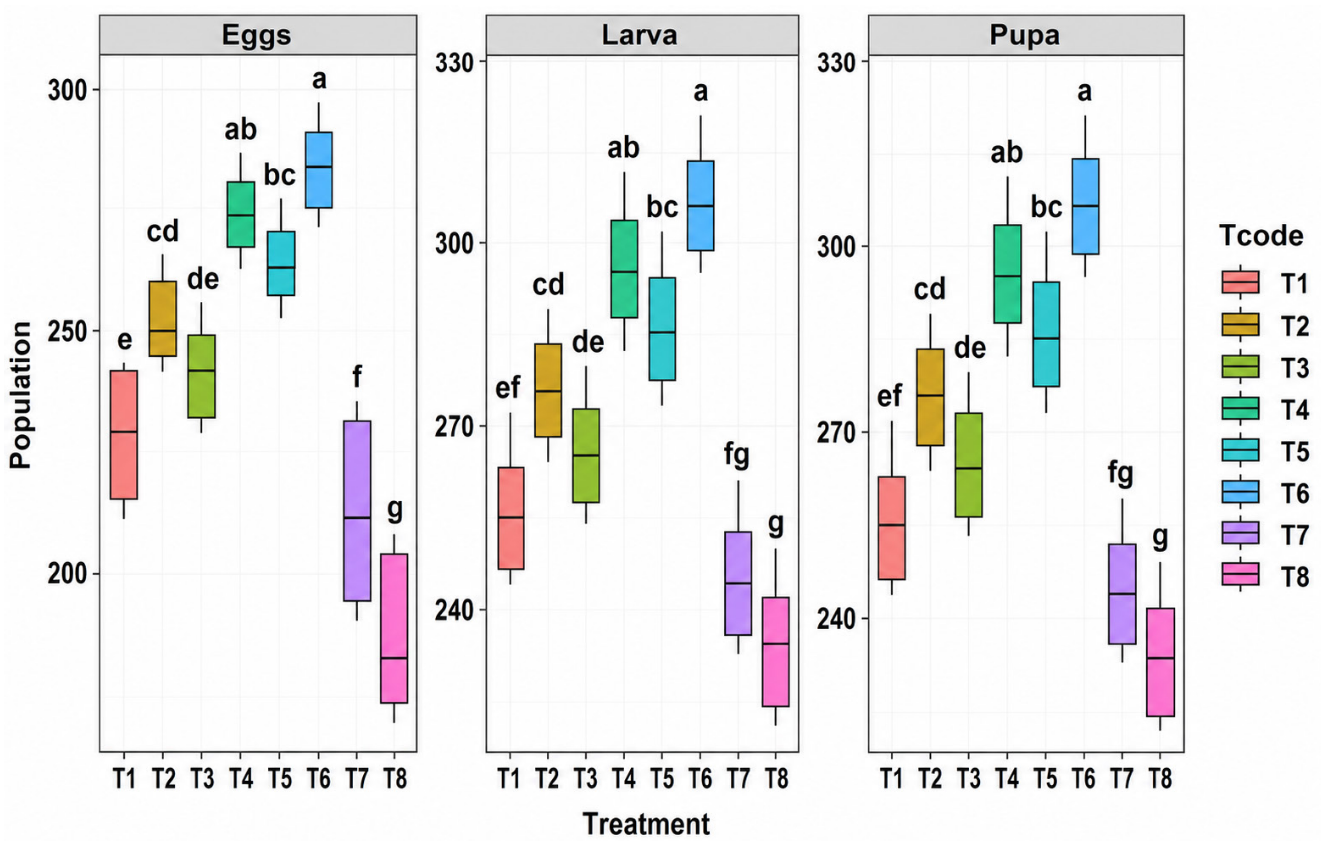

Fig 3. Box plot shows the bee biology, population of egg, larva, and pupa (mean ± standard error) recorded after the consumption of various artificial nectar supplements at weekly intervals during summer and winter 2022. The different small letters within each data represent statistically significant differences ($p < 0.05$).

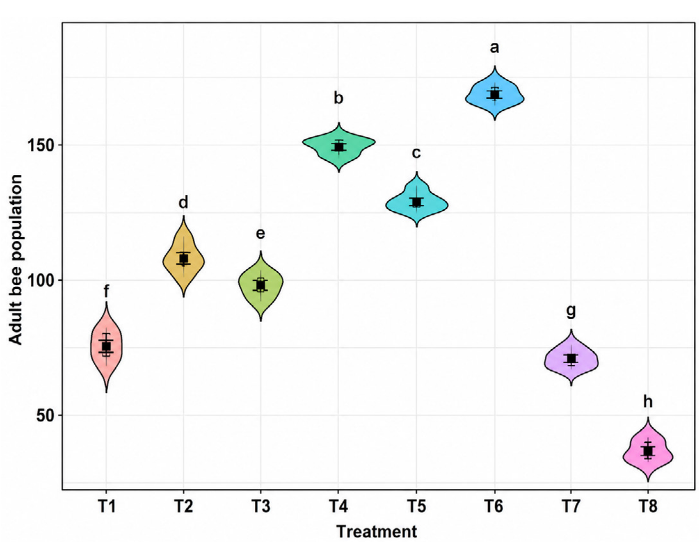

Fig 4. The violin plot shows the adult bee population (mean ± standard error) recorded after the consumption of various artificial nectar supplements at weekly intervals during summer and winter 2022. The different small letters within each data represent statistically significant differences ($p < 0.05$).

Pollen and Nectar

Significant difference ($p < 0.05$) were observed among the treatments (T1 to T8) for pollen and honey cell of bees colonies fed with artificial nectar substitutes (**Fig 5**). For pollen cells, the highest population was recorded in T6 (220 ± 1.3 no. of cells), which was statistically superior followed by T2 also showed relatively high pollen cell count and T8 had the lowest pollen cells. For honey cells, T7 (357 ± 3.2 cells) showed the highest count, significantly higher than all other treatments, followed by T6 and T4. The lowest honey cell was recorded in T8.

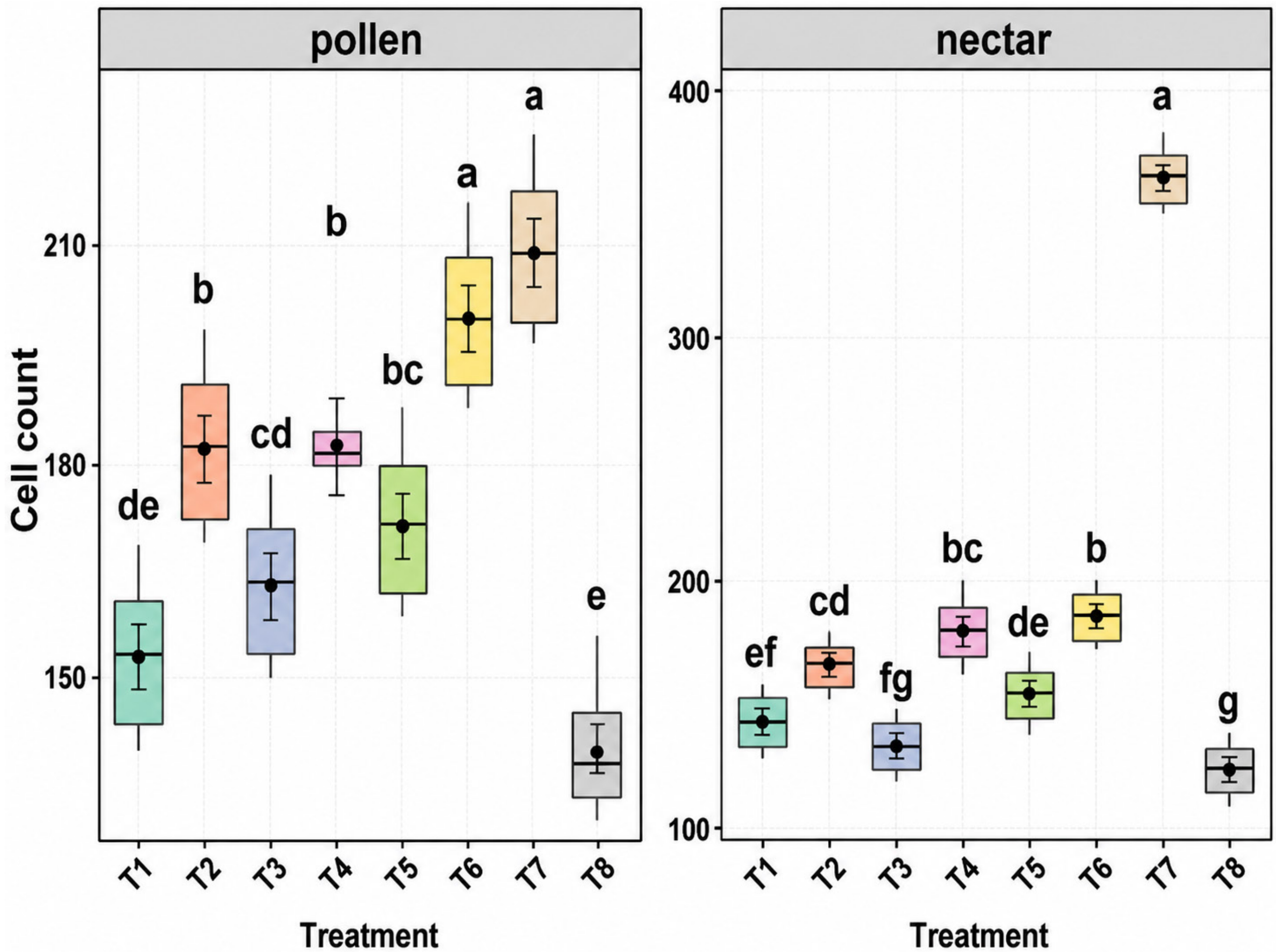

Fig 5. The box plot shows the number of pollen and nectar cells (mean ± standard error) recorded after the consumption of various artificial nectar supplements at weekly intervals during summer and winter 2022. The different small letters within each data represent statistically significant differences (p < 0.05).

Foraging activity

Bee foraging activity showed significant variation (p<0.05) among treatments and between time intervals (**Fig 6**). The analysis of variance revealed that both treatment and time of day had significant effects on the foraging activity of bee colonies fed artificial nectar substitutes. Across all treatments, bee foraging activity was consistently higher at 6.00 AM than at 4.00 PM. Among the treatments, T6 recorded the highest foraging activity in outgoing bees (66 ± 4.3 bees at 6.00 AM and 63 ± 6.4 bees at 4.00 PM), incoming bees with pollen (97 ± 3.6 bees at 6.00 AM and 87 ± 2.9 bees at 4.00 PM) and nectar load (77 ± 5.2 bees at 6.00 AM and 73 ± 2.1 bees at 4.00 PM) followed by T7, whereas the lowest foraging activity was consistently recorded in T8.

Correlation between weather parameters and foraging activity

According to Figure 7, during summer 2022, temperature (both max and min) and wind are negatively correlated with most foraging activities. Sunshine hours have a positive correlation with nectar and pollen collection, and rainfall shows a positive correlation with outgoing bees. Relative Humidity (both max and min) shows a strong positive correlation with most foraging activity (**Fig 7A**). During winter 2022, wind has a very strong positive correlation with all the foraging activity. Temperature (both max and min) has also shown a positive correlation. Sunshine hours and relative humidity (both max and min) show strong negative correlation with all foraging activity (**Fig 7B**).

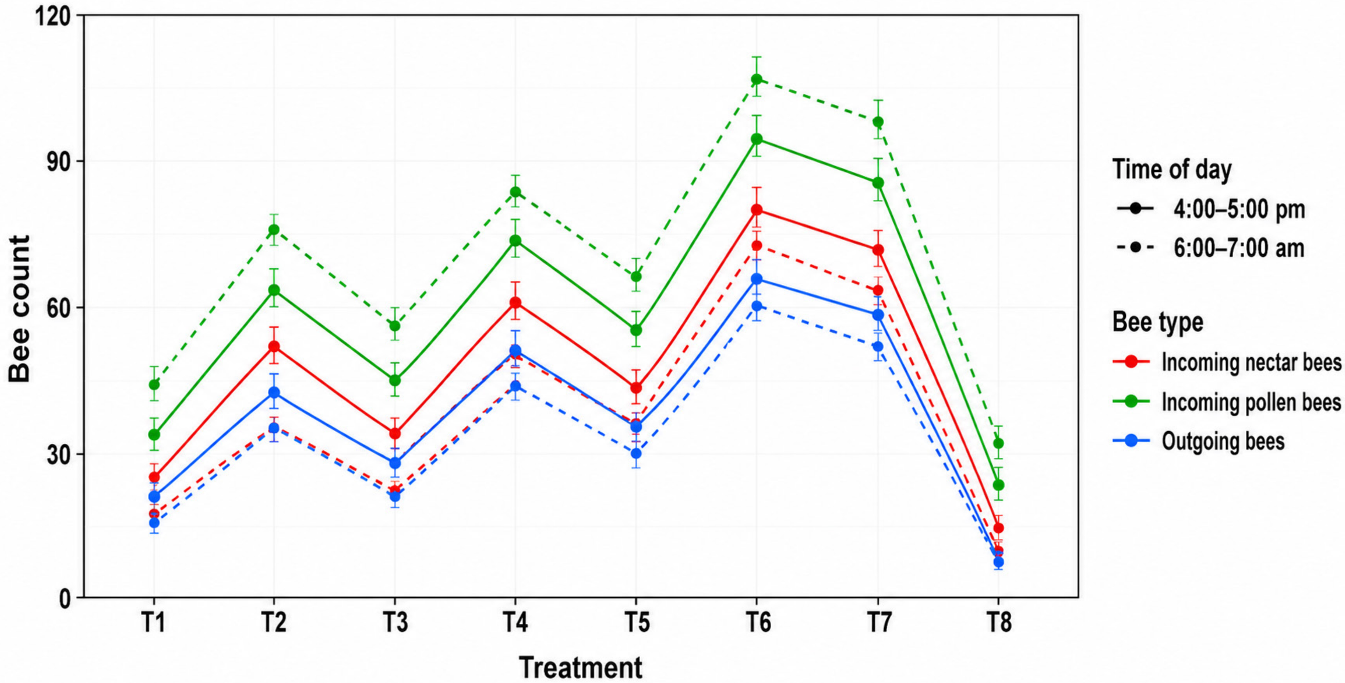

Fig 6. The line graph shows the foraging activity (mean ± standard error) after consumption of various artificial nectar supplements. The mean numbers of outgoing bees and of bees with pollen and nectar were recorded from 6.00 to 7.00 AM and from 4.00 to 5.00 PM at weekly intervals during summer and winter 2022.

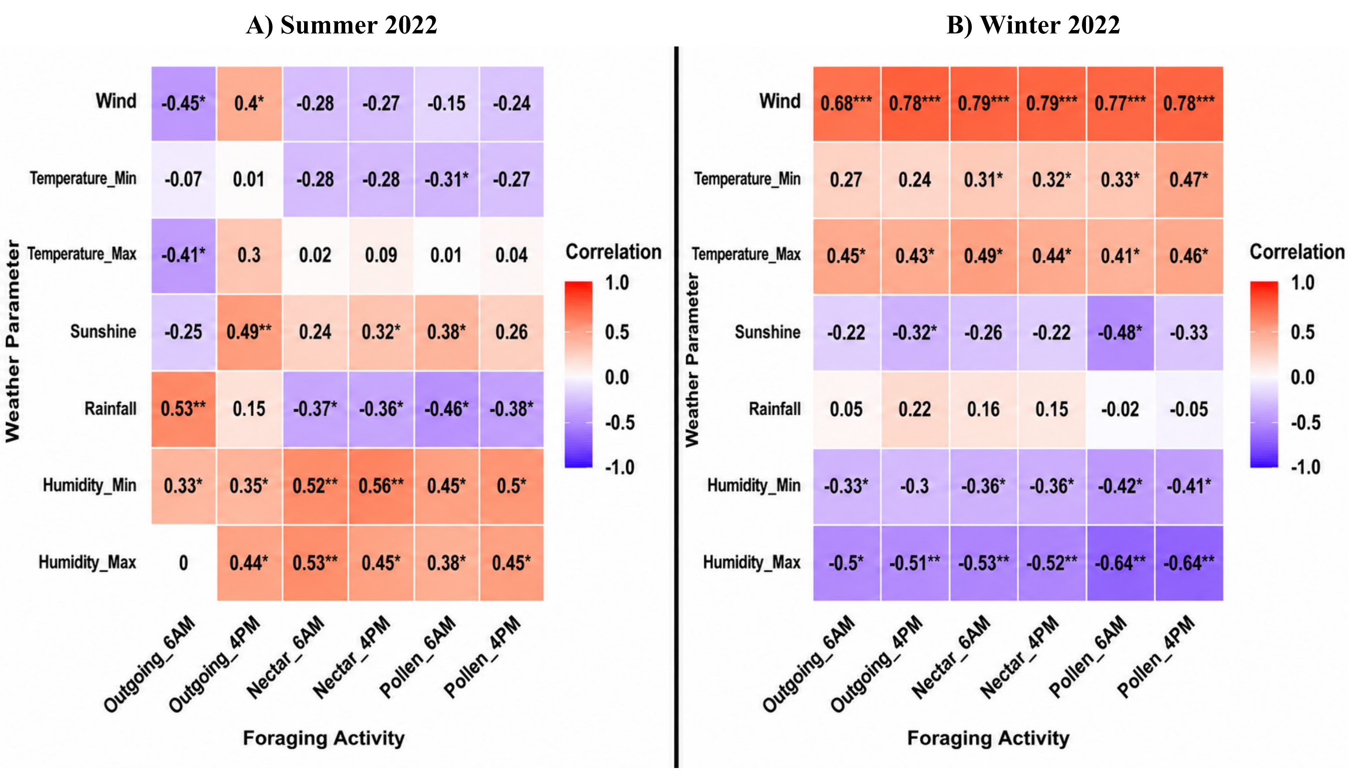

Fig 7. The heatmap shows the Pearson correlation coefficients among weather factors (maximum and minimum temperature, maximum and minimum relative humidity, rainfall, wind velocity, and solar radiation) and foraging activities (outgoing bee, pollen, and nectar foragers at 6.00 AM and 4.00 PM). The asterisks indicate significant correlations (*p < 0.05, **p < 0.01).

Discussion

The feeding preferences of Indian honey bees for various artificial nectar substitutes were evaluated during summer and winter 2022 at PAJANCOA&RI, Karaikal. Among the treatments, T6 – pumpkin juice + sugar syrup + turmeric powder + vitamin E consistently performed best across all recorded parameters. These findings further supported the idea that honeybees might prefer banana and pumpkin syrups because of the natural sugars and unique flavors they provide, leading them to consume more of these syrups than rice and maize flour syrups (Neupane & Thapa, 2005; Hranssnig & Crailsheim, 2005). Upadhya (2003) also indicated that bees showed greater affinity for sweet pumpkin syrup than for temperate fruit pulp, turnip, and *Malus* syrups. The present study corroborated these earlier findings, particularly highlighting pumpkin juice's superior performance among the tested artificial nectar substitutes. This also indicates that pumpkin-based supplements, along with syrup, can serve as effective diets for honey bees during resource-scarce periods.

The results consistently demonstrated that pumpkin juice was the most effective treatment and performed superiorly across all the life stages from eggs, larvae, pupae, and adults, suggesting that it provides a unique and highly beneficial nutritional profile for honey bees. While the exact composition was not specified, pumpkin is rich in vitamins, minerals, and complex carbohydrates, which are essential for bee health and brood rearing. The high egg population in T6, followed by equally high larval and pupal counts, indicates that this treatment successfully stimulated the queen's egg-laying activity and supports the vigorous development of brood. This is consistent with the studies by Sultana et al. (2024), who observed that bee colonies receiving pumpkin syrup showed a significant 71.36% increase in brood cell numbers. Depending on each syrup's unique nutritional makeup, the effects of adding banana, pumpkin, maize flour, and rice flour syrups as supplemental food on the development of brood cells in honeybee colonies may differ. Protein, lipids, and carbohydrates are necessary for honeybee colonies to produce the best possible brood cell proliferation. The high concentrations of natural sugars and minerals in pumpkin syrups are well known. According to the study, pumpkins have protein and carbohydrate ratios. It has been found that these syrups benefit the development of brood cells, leading to increased production and faster growth. Therefore, to support brood cell development and sustain the colony's healthy growth, it is important to carefully analyze each individual's food consumption, ensure adequate nutrition, and manage supplemental food effectively. Also, discover that the number of bees on frames increases significantly when they are fed a high-protein diet (Ricigliano et al., 2022).

By providing extra nutrients needed for pollen collection and storage, supplemental diets may affect the growth of pollen cells in honeybee colonies. Pollen is an essential protein source for the colony's overall health and brood development. The main components for honeybee pollen cell development are protein and carbohydrates (Khalifa et al., 2021). The results show that consuming pumpkin syrup increases the number of pollen cells and that pumpkin has the ideal carbohydrate-to-protein ratio for pollen formation. Nonetheless, bees may be drawn to forage more vigorously by pumpkin syrup, which is high in carbohydrates and micronutrients. This would enhance the amount of pollen collected and promote the development of pollen cells. Pollen cell development promotes the growth and viability of the colony's output by ensuring sufficient pollen resources within the hive (Sultana et al., 2024). Pande et al. (2015) demonstrated a significant enhancement in pollen and honey storage in honey bee colonies fed various fruit juices, such as banana syrup, which outperformed those fed pumpkin, papaya, grape, and guava syrups. Singh and Singh (2012) reported maximum brood activity and honey storage with neem fruit pulp, while Pande and Karnatak (2013) observed increased honey and pollen storage with temperate fruit syrups. Sultana et al. (2024) observed an increase in the number of honey cells when the colony was fed pumpkin syrup. These findings suggest that the nutritional composition of pumpkin-based feed supplements may offer superior benefits for the colony resource accumulation compared to other tested sugar sources.

Artificial nectar substitutes on the foraging activity of honey bees revealed a clear difference in outgoing and incoming bee populations, including pollen and nectar gatherers. These findings are consistent with those of Arenas and Kohlmaier (2019), who studied the quality of the nectar given inside a hive, which altered the rate of incoming pollen foragers, pollen, and non-pollen foragers, before and after the hives were fed either a 3 or a 50% w/w sugar solution. Similarly, Pande et al. (2015) revealed the significant increase in foraging activity including incoming bees and outgoing bees (No. of bee/min) in colonies fed with banana syrup was followed by papaya, sugar, grapes and guava syrups. Pande and Karnatak (2013) also showed the feeding with temperate fruit syrups increased foraging activity, further supporting the role of alternative supplements in stimulating bee foraging behaviour. Seasonal effects on foraging behaviour have also been reported. Hemalatha et al. (2018) reported that the maximum foraging activity of 10.30%, 9.91% and 9.26% was recorded in winter season 3rd, 4th and 5th standard weeks (SW), respectively. During 1st (47.69%) to 5th (48.61%) SWs the outgoing bee population outnumbered the nectar gatherers.

The negative correlations showed that wind and high temperatures significantly reduced foraging activity. This result is consistent with previous research indicating that high temperatures and winds make it harder for bees to fly and require more energy, thereby lowering their foraging efficiency (Clark & Robert, 2018). On the other hand, nectar and pollen gathering were positively correlated with longer daylight hours, suggesting that bee activity is higher in clear, sunny conditions that are ideal for flight and flower availability. Although it may seem counterintuitive, the positive relationship between relative humidity and foraging activity may be explained by its effects on nectar viscosity and availability; higher humidity may prevent nectar from drying out and increase foragers' access to it (Wcislo & Cane, 1996).

Conclusion

This study on artificial nectar supplements demonstrated that fruit juices derived from pumpkin-based formulations were superior compared to conventional sugar syrup in sustaining honey bee colonies during dearth periods. Pumpkin juice significantly enhanced honey bee consumption rate, brood and adult worker bee populations, pollen and nectar storage, and foraging activity, thereby ensuring colony strength and productivity. Moreover, correlations between weather parameters and foraging behavior underscore the importance of adjusting feeding strategies to local climatic conditions. However, integrating nutrient-rich fruit juices not only enhances honey bee health but also offers a sustainable way to utilize agricultural products. Implementing such creative feeding techniques can empower beekeepers in regions like Karaikal to effectively manage colonies, thereby mitigating the impacts of the dearth season and ensuring that pollination services are provided more effectively.

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Authors' Contributions

MK: conceptualization, resources, methodology, writing-review & editing, project administration, funding acquisition.
PA: methodology, investigation
KN: writing-original draft, writing review & editing, visualization.

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