



Evaluation of Alternative Sugar Supplementary Feeding during the Off-Season on Brood Development, Colony Performance, Honey Production, and Economic Efficiency of Honeybee colony (*Apis mellifera bandasii*) in western Oromia, Ethiopia

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Abstract

Supplementary feeding during dearth periods is an important management practice for maintaining honeybee colony strength and productivity. This study comparatively evaluated the effects of alternative sugar syrup supplements on colony performance, honey yield, and economic efficiency of *Apis mellifera bandasii* under dearth-period conditions. The study was conducted to evaluate the effect of dearth period alternative sugar source supplementary feeding of honeybee colonies on brood development and honey production, as well as the economic advantage. Key data collected included feed consumption, brood developments, adult population, honey storage area, and honey yield. The result indicates that Sugar syrup was the most consumed feed (98.30%), closely followed by banana (97.32%) and maize (96.73%) syrups, whereas pumpkin syrup showed substantially lower intake (55.75%). High consumption of Sugar, banana, and maize syrups reflects strong colony preference and productivity, whereas Lower intake of pumpkin syrup limited its overall benefits. Sugar, banana, and maize syrups delivered similar gains in colony strength and productivity, while pumpkin syrup resulted in consistently underperformed across these measures, failing to support honeybee colony performance. This results highlight the top supplements' equivalence in sustaining hive vitality during forage shortages. Sugar syrup produced the top honey yield (22.06 kg/colony) but had the weakest cost-benefit ratio due to elevated expenses. Banana and maize syrups matched performance at lower costs, yielding the best financial returns. Pumpkin syrup, though cheap, offered poor biological results and low acceptance, making it impractical. Therefore, banana and maize syrups emerge as sustainable, affordable substitutes for sugar syrup in dearth period management.

Keywords: *Apis mellifera bandasii*; alternative sugar syrup; colony performance; dearth period.

Introduction

Honeybees (*Apis mellifera* spp.) play a vital role in agriculture and ecosystems by providing pollination services alongside hive products like honey, beeswax, and propolis. They require a balanced diet of carbohydrates, proteins, lipids, minerals, vitamins, and water to survival, growth, reproduction, and colony maintenance (Standifer *et al.*, 1977; Tolera, 2014). Carbohydrates from nectar and honeydew fuel adult bees, while pollen supplies proteins essential for brood rearing and the development of hypopharyngeal glands in nurse bees (Javaheri *et al.*, 2000).

Floral dearth periods cause, nutritional stress resulting in brood rearing reduction, population decline, and weakened colonies (Neupane & Thapa, 2005; Sihag & Gupta, 2013). This seasonal shortage of forage is one of the most critical challenges in beekeeping, especially in tropical and sub-tropical regions such as Ethiopia, where climatic fluctuations and anthropogenic activities exacerbate forage scarcity (Tolera, 2014). Supplementary feeding during such periods is therefore indispensable to sustain colony viability, stimulate brood rearing, and ensure early foraging strength in the subsequent honey flow season (Somerville & Collins, 2007; Prakash *et al.*, 2007).

Supplementing with carbohydrate feeds during dearth sustains colonies, boosts early brood rearing, and enhances foraging readiness. Recent studies highlights sugar syrup, banana syrup, maize syrup, pumpkin syrup, and others as effective options for improving brood area, honey yields, and colony performance. Affordable local alternatives like banana and maize syrups cut costs while matching sugar syrup's benefits, outperforming less palatable options like pumpkin syrup. Low-cost substitutes address rising sugar prices and supply issues for beekeepers (Sultan *et al.*, 2024).

The success of supplemental feeding, especially using locally available or low-cost alternatives, is crucial for beekeepers facing higher sugar prices and supply constraints. Therefore study aimed to

evaluate the effects of dearth-period sugar supplementary feeding on honeybee colonies by comparing alternative carbohydrate sources in terms of feed intake, brood development, adult bee population, honey storage area, and honey yield and to evaluate the economic feasibility and cost-benefit efficiency of these supplementary feeds for sustainable colony viability during the off-season.

Materials and Methods

Study Site

The experiment was conducted at the Bako Agricultural Research Center (BARC) in western Oromia, Ethiopia, a mid-altitude sub-humid region at 260 km west of Addis Ababa (9°06' N, 37°09' E, 1650 m elevation) , at an altitude of about 1650 meters above sea level. Annual rainfall averages 1200 mm, mostly from June to September, with mean temperatures around 27°C (22–31°C range) and reddish-brown clay-loam soils dominant (BARC, 2003).

Establishing experimental colonies and setting up

A total of sixteen honeybee colonies were established in Zander hives during the active season (September) and each colony was numbered and labeled. All transferred colonies were fed on sugar syrup (1:1 sugar to water ration). To keep the uniformity of experimental colonies, all colonies were inspected and all resources such as brood, pollen, nectar, and honeybee populations were equally distributed for each colony and they were assigned randomly to four different treatments in a randomized complete block design (RCBD) with four replicates each.

Preparation of Experimental Diets

Four carbohydrate syrups, sugar (control), maize, banana, and pumpkin, were selected after preliminary tests for bee preference, availability, and cost, with sugar content verified pre-feeding. Each syrup was prepared with 20 g of natural honey for palatability and nutritional value, in 1-liter batches.

Table 1; Experimental diets formulation

Treatments	Diet Type	Description of Treatment
T1 (Control)	Sugar Syrup	1:1 sugar–water solution supplemented with 20 g natural honey
T2	Maize Syrup	Filtrate of 100 g maize powder + 200 g sugar + 20 g honey
T3	Banana Syrup	Filtrate of 100 g ripe banana + 200 g sugar + 20 g honey
T4	Pumpkin Syrup	Filtrate of 100 g boiled pumpkin + 200 g sugar + 20 g honey

Feeding of diets

Feeding was conducted inside the hive using a division board feeder at a rate of 30 ml of syrup per frame of bees every three days. Each colony received a total of seven feedings during the trial period.

Colony Preparation and Feeding

Experimental colonies were standardized to five frames covered with adult bees and 3.5 frames of brood, each headed by a queen of similar age and vigor. Feeding was conducted inside the hive using a division board feeder at a rate of 30 ml of syrup per frame of bees every three days. Each colony received a total of seven feedings during the trial period. The amount of syrup consumed by each colony was determined by subtracting the unconsumed syrup remaining in the feeder after each feeding session. Data were collected at weekly intervals to assess the effects of the different feeding materials on colony performance.

Data Collection and Measurement Diet consumption

The daily consumption of each diet was calculated by measuring the weight difference of the diet before and after feeding in grams, recorded every three days for each colony.

Brood area, pollen and honey storage

The comb areas occupied by capped and uncapped worker brood, pollen, and honey store

were measured every 21 days by overlaying a grid premarked 5 cm by 5 cm on each side of every brood frame (Delaplane *et al.*, 2013; Alaux *et al.*, 2010; Seeley, 1995).

Adult bee population

The adult honeybee population was estimated at every 21 days by counting the total number of frames entirely covered with honeybees which is the developmental period of worker honeybees.

Honey yield

Honey yield data were collected at the colony level by harvesting only fully capped frames at the same time across treatments. Full frames were weighed before extraction and empty frames after extraction, with the difference recorded as honey yield per colony. Alternatively, extracted honey from each hive was weighed directly using a calibrated digital scale. All measurements were recorded in kilograms per colony per harvest period.

Data Analysis

Collected data were analyzed using Analysis of Variance (ANOVA) under the General Linear Model (GLM) procedure of SAS software version 9.3. The treatment means were separated using the Least Significant Difference (LSD) and Tukey's tests at a 5% level of significance.

Partial budget analysis

Partial budget analysis was used to evaluate the economic feasibility of different supplemental feeding treatments for honeybee colonies under on-station conditions by focusing on variable costs and returns. Net income (NI) was calculated as the difference between total return (TR) and total variable cost (TVC) following Ehui et al. (1992) ($NI = TR - TVC$). Total return represents the monetary value of honey yield per colony, computed as average yield multiplied by market price, while total variable cost includes expenses related to syrup preparation and feeding. To compare treatments with the control (sugar syrup), the change in net income (ΔNI) was calculated as the difference between change in total return (ΔTR) and change in total variable cost (ΔTVC). This method allows clear comparison of profitability among treatments. A positive ΔNI indicates higher economic benefit over the control, while a negative value shows reduced profitability.

Results and Discussion

Diet consumption rate

The result presented in table 2 indicated the mean of feed consumption rates that was supplied during dearth period. The result indicated that sugar syrup achieved the highest intake at

98.30%, with banana syrup (97.32%) and maize syrup (96.73%) nearly matching it, while pumpkin syrup lagged far behind at 55.75%. These results suggest that sugar syrup remains the most efficient and preferred artificial feed, while banana and maize syrups represent promising local alternatives when sugar syrup is costly or unavailable. Pumpkin syrup, however, appears less suitable due to its limited acceptance and low utilization. The higher consumption rate of sugar, banana, and maize syrups can be attributed to their higher carbohydrate concentrations and simpler sugar profiles, which are more readily metabolized by honeybees (Ghosh & Jung, 2017; Abdel-Rahman, El-Naggar & Abdel-Kader, 2020). Banana and maize syrups, derived from local fruits and cereals, contain simple sugars and micronutrients that may mimic natural nectar components, enhancing their palatability and suitability as alternative feeds (Felicoli, Sabatini & Casati, 2007). Conversely, the lower consumption rate of pumpkin syrup could be due to its higher viscosity, possible presence of less desirable flavor compounds, or reduced sugar content (Nicolson, 2011; Taha, Hussein & El-Naggar, 2019). These findings align with previous studies (Abd El-Wahab & Zidan, 2018; Guler & Bakan, 2022) reporting that sucrose-based feeds generally promote better intake and colony performance compared to more complex carbohydrate syrups.

Table 2. Feeding Intake of honeybee colonies

Treatments		Given amount (g)	Consumed amount (g)	Leftover amount (g)	Utilized amount (%)
Sugar	syrup	1050	1032.17	17.83	98.30
(control)					
Banana	syrup	1050	1021.86	28.14	97.32
Maize	syrup	1050	1015.63	34.37	96.73
Pumpkin	syrup	1050	585.37	464.63	55.75

Combined Analysis Of Variance of Four Alternative Sugar Syrup Supplementary Feeds

The analysis of variance (ANOVA) revealed that treatment had a significant effect on brood area

(BA), adult population area (APA), honey storage area (HSA, and honey yield (HY) (Table 3). Specifically, the mean squares for treatment were significant at different confidence levels: BA ($MS = 3.898, p < 0.01$), APA ($MS = 3.111, p < 0.001$),

HAS (MS = 1.041, $p < 0.05$), and HY (MS = 4.194, $p < 0.01$). This indicates that the type of feeding syrup significantly influenced colony development and productivity parameters. In contrast, block effects were not significant for any of the measured variables (BA, APA, HAS, and HY), suggesting that environmental or positional variation among blocks did not notably affect the outcomes.

Overall, the significant treatment effects on most measured variables confirm that **alternative sugar supplementary feeding enhances colony performance, promoting adult bee population, brood development, honey storage, and final honey yield.** These results demonstrate that

alternative syrups can serve as effective carbohydrate supplements to sustain colony activity and productivity, particularly during floral scarcity.

These results confirm that the type of supplemental syrup significantly influences colony development and productivity, with alternative sugar supplements enhancing brood development, adult bee population, honey storage, and final honey yield. This highlights the potential of alternative syrups to sustain colony activity and productivity during periods of floral scarcity (DeGrandi-Hoffman, Chen & Huang, 2010).

Table 3: Combined analysis of variance of four alternative sugar syrup supplementary feeds

Sources Of Variation	DF	Mean Squares			
		BA	APA	HSA	HY
Treatment	3	3.898**	3.111***	1.041*	4.194**
Block	3	0.132 ^{NS}	0.262 ^{NS}	0.09 ^{NS}	0.151 ^{NS}
Error	9	0.378	0.175	0.157	0.392

Where *, **, and *** show significance at 0.05, 0.01, and 0.001% respectively, NS-not significant, DF-degree of freedom.

Effect of feeding treatments on Brood development and Adult honeybee population

The effects of nectar source supplementary diets on brood area (BA) and adult population are summarized in Table 4. Colonies fed with sugar syrup had built more brood area (10.63 ± 0.22 cm²) followed by banana syrup (10.42 ± 0.58 cm²), maize syrup (10.15 ± 0.71 cm²) and pumpkin syrup (8.46 ± 0.49 cm²) (Table 4). Similarly colony fed with sugar syrup built more adult bee population (104.55 ± 0.54 cm²) followed by banana syrup (104.51 ± 0.34 cm²), maize syrup (104.33 ± 0.54 cm²), which were significantly higher than that observed in colonies fed pumpkin syrup (102.46 ± 0.27 cm²) ($p < 0.05$). Brood development and adult population responded strongly to alternative sugar supplements, reflecting the importance of

adequate carbohydrates and nutrients for colony buildup (Mattila & Otis, 2006; DeGrandi-Hoffman *et al.*, 2010). Colonies fed with banana and maize syrups built more brood areas and adult populations than colonies fed on pumpkin syrup. This might be due to higher sugar content and better palatability. These findings align with (Amdam & Omholt, 2002; Mutsaers *et al.*, 2005; Di Pasquale *et al.*, 2013; Belina *et al.*, 2021) colony fed with energy source built more brood area and adult bee population. Conversely, the lowest brood area and adult bee population built with colony fed with pumpkin syrup, which aligns with findings that nutrient-poor diets delay brood growth and reduce colony strength (Abd El-Wahab *et al.*, 2017; Abou-Shaara, 2014). Alternative carbohydrate sources can sustain colony development when properly formulated (Felicoli *et al.*, 2007; Kumari & Kumar, 2019).

Table 4: Effect of Feeding Treatments on Brood and Adult Population Area (Mean $\pm$ SD)

Treatment	BA (Cm ²) at the beginning	BA (Cm ²) at the end (Mean $\pm$ SD)	APA (Cm ²) at the beginning	APA (Cm ²) at the end (Mean $\pm$ SD)
Sugar syrup (control)	8.625	10.63 $\pm$ 0.22 ^a	79.2	104.55 $\pm$ 0.54 ^a
Banana syrup	8.625	10.42 $\pm$ 0.58a ^b	79.2	104.51 $\pm$ 0.34 ^a
Maize syrup	8.625	10.15 $\pm$ 0.71 ^b	79.2	104.33 $\pm$ 0.54 ^a
Pumpkin syrup	8.625	8.46 $\pm$ 0.49 ^c	79.2	102.46 $\pm$ 0.27 ^b

Where BA' brood area, APA- adult population area

Effect of feeding treatments on Honey Storage Area and Honey Yield

The effect of feeding treatments on honey storage area and honey yield are presented in Table 5. Analysis of variance (ANOVA) showed no significant difference ($P>0.05$) across treatment groups regarding to honey storage area and honey yield except the control one (Table 5). Colonies fed with sugar syrup had more honey storage area (30.83 ± 0.18 cm²) compared to banana syrup (30.73 ± 0.15 cm²), and maize syrup (30.51 ± 0.31 cm²). However, colonies supplemented with pumpkin syrup exhibited significantly lower honey storage area (29.70 ± 0.59 cm²). Similarly, colonies fed with sugar syrup produce more amount of honey yield syrup (22.06 ± 0.59

kg/colony) followed by banana syrup (21.77 ± 0.72 kg/colony), and maize syrup (21.50 ± 0.49 kg/colony). The lowest honey yield (19.78 ± 0.47 kg /colony) was recorded from colonies fed with pumpkin syrup (Table 5). This might be due to differences in sugar composition, palatability, or nutritional quality of pumpkin syrup, which could affect forager acceptance and nectar processing efficiency (Mattila & Otis, 2006; Mahmoud, 2013). The findings demonstrate that colonies supplementation with nectar source diets supports honeybee colonies for comparable honey storage and production. This results aligning with previous research emphasizing the importance of carbohydrate-rich diets in promoting colony productivity (DeGrandi-Hoffman *et al.*, 2010; Somerville, 2005).

Table 5. Feeding Treatments' Effect on Honey Storage Area and Honey Yield

Treatment	HSA (cm ²) (Mean $\pm$ SD)	HY (Kg) at harvesting time (Mean $\pm$ SD)
Sugar syrup (control)	30.83 $\pm$ 0.18 ^a	22.06 $\pm$ 0.59 ^a
Banana syrup	30.73 $\pm$ 0.15 ^a	21.77 $\pm$ 0.72 ^a
Maize syrup	30.51 $\pm$ 0.31 ^a	21.50 $\pm$ 0.49 ^a
Pumpkin syrup	29.70 $\pm$ 0.59 ^b	19.78 $\pm$ 0.47 ^b

Where HAS-Honey storage area, SD- Standard deviation

Partial budget analysis

The cost–benefit analysis (Table 6) revealed significant differences in the economic efficiency of the various syrup treatments fed to honeybee colonies. The pumpkin syrup treatment showed the highest cost–benefit ratio (CBR = 9.63). It was noted that bees consumed pumpkin syrup less

readily compared to banana and maize syrups. The lower consumption of pumpkin syrup, despite its lower cost, likely contributed to the slightly reduced honey yield (19.78 kg) observed in this treatment. This suggests that palatability and acceptance by the bees are critical factors influencing the effectiveness of supplemental feeding (DeGrandi-Hoffman *et al.*, 2010).

Conversely, banana and maize syrups, which are more locally available and preferred by bees, resulted in higher honey yields (21.77 kg and 21.5 kg, respectively) and also demonstrated excellent economic efficiency (CBRs of 7.78 and 9.59). Their higher acceptance by the colonies likely promoted better colony health and productivity, translating into increased honey production (Mattila & Otis, 2006; Abd El-Wahab et al., 2017). The sugar syrup (control), while producing the highest honey yield (22.06 kg), incurred substantially higher input costs, resulting in the lowest economic efficiency (CBR = 3.81). This highlights that a high yield alone does not

guarantee profitability, particularly when input costs are elevated (Seeley, 1995).

The findings also emphasize the advantage of using locally sourced carbohydrate supplements. Banana and maize syrups, readily accessible in the study region, reduce dependency on commercially processed sugar, potentially lowering the environmental footprint and supporting local economies. This aligns with sustainable apiculture practices that encourage resource utilization within the bees' natural foraging range (Abd El-Wahab et al., 2017).

Table 6. Cost of supplemental feeding during the dearth season

Treatment	Ingredient	Given Amount (kg)	Cost/kg (ETB)	Total Cost (ETB)	Honey Yield (kg)	Benefit (ETB)	Cost–Benefit Ratio (CBR)
Sugar syrup	Sugar	28	155	4340	22.06	16545	3.81
Banana syrup	Banana	28	60	2100	21.77	16328	7.78
	Honey	0.56	750				
Maize syrup	Maize	28	45	1680	21.5	16125	9.59
	Honey	0.56	750				
Pumpkin syrup	Pumpkin	28	40	1540	19.78	14835	9.63
	Honey	0.56	750				

Conclusion and Recommendation

The study evaluated that supplemental feeding with sugar syrup, banana syrup, and maize syrup significantly improves honeybee colony performance in terms of feed utilization, brood development, adult bee population, honey storage, and honey yield. Sugar syrup remains the most efficiently utilized feed and produces the highest honey yield; however, it incurs the highest input cost, resulting in the lowest economic efficiency. Banana and maize syrups, which are locally available and well accepted by the bees, provided comparable colony performance and honey yields to sugar syrup but with substantially lower costs, resulting in superior cost–benefit ratios. These syrups represent promising, sustainable, and cost-

effective alternatives to conventional sugar syrup, particularly in regions where sugar is expensive or scarce. Pumpkin syrup showed the lowest acceptance by colonies and resulted in significantly reduced brood development, adult population, honey storage, and yield despite its low cost. This indicates that pumpkin syrup is less suitable as a supplementary feed due to its poor palatability and nutritional profile. Therefore, **banana and maize syrups** can be recommended for feeding honeybee colonies during dearth periods to sustain colony strength without compromising honey production or profitability. Conduct further research to optimize nutrient profiles in fruit and cereal-based syrups, potentially through fortification with pollen substitutes or vitamins.

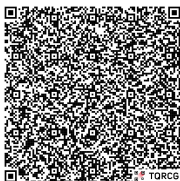
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