International Journal on Food, Agriculture, and Natural Resources
Volume 6, Issue 4, Page 152-158
ISSN: 2722-4066
http://www.fanres.org

Original Paper

Effect of supplementary feeding on honeybee colonies performance in Wag-Lasta area, North-Eastern Ethiopia

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Received: 17 October 2025; Revised: 15 December 2025; Accepted: 24 December 2025
DOI: *https://doi.org/10.46676/ij-fanres.v6i4.578*

***Abstract*—Honey bees need pollen and nectar to survive, and strong colonies before colony buildup season require proper feeding to support brood development. This study evaluated the impacts of supplements with varying protein content on colony performance, brood rearing, and honey production. Sixteen colonies were divided into four groups: three treatments and one control, each with four replicates. Treatments included Acacia pod flour: pollen (9:1 w/w), pea flour: pollen (9:1 w/w), and a mix of Acacia pod and pea flour: pollen (9:1 w/w); the control group received no supplementation. Feed was given in feeder supper box hives and measured every 7 days, with intake and refusal recorded. Hive resources such as pollen, nectar, brood space (cm2), adult bees, and honey were assessed using a frame-sized grid meter at the Gazgibilla apiary research site. Feed types were selected through palatability testing. The mixture of Acacia pod and pea flour had the highest consumption (243.19 g/day), brood area, pollen area, nectar area, colony size (frames covered with bees), and honey yield (35 kg/colony). The control group had the lowest values on all measures. Supplementary feeding increased honeybee populations and improved colony performance during dearth periods. The author recommends the commercial use of the Acacia and pea diet mix for sustained colony growth during the dearth periods.**

Keywords*—*Acacia pod, Apis mellifera monticolla, Colony Performance, Pollen substitute, Supplementary Feed

I. INTRODUCTION

Nutrition is a requirement for the survival of every living organism. Honeybees meet their nutritional needs from natural floral sources under normal conditions. In cases where there are insufficient floral resources, additional feeding is required for the colonies [2,3].

In the beekeeping sector, pollen and supplementary feeding with honey are used to prevent hunger and to develop a higher population in bee colonies in spring, by providing for brood formation in autumn and the beginning of winter in the young worker bee population, and in queen and drone breeding, to have healthier colonies and prevent loss of bees after using agricultural chemicals in plant production [14]. Especially, the composition and ratio of nutrients affect the longevity of honey bees [4,23]. Seasonal and climatic changes (extreme temperature, precipitation, hail, etc.) cause significant reductions in floral resources [1,37].

Beekeepers must secure nectar-source plants to manage their honey bees, select apiary sites carefully, and move beehives to a new apiary during the flowering season for honey bees to forage [27]. Honeybees are well known for their commercial products, playing increasing roles in income generation, healthy food, and medicinal values [23].

The development of a pollen supplementary diet for honey bees has been an area of curiosity to the beekeeping industry. Thus, appropriate nutrition, provided by pollen and nectar, is essential for honeybee health, development, survival, and honey production. Pollen is the major source of protein for honeybee colonies and is used to feed the newly reared larvae and young bees, providing the structural elements necessary for muscles and glands. Particularly, extraordinary pollen ingesting by adult worker bees in the first few days after emergence enables them to develop their mandibular and hypopharyngeal glands, which produce royal jelly for feeding the newly reared brood and other colony members [20]. Honeybees necessitate nectar as a carbohydrate source and pollen as a protein, amino acid, lipid, sugar, starch, vitamin, and mineral source to sustain hive function and to motivate foraging flights [15].

The bees equally accept the pollen substitute diet and pollen. The pollen substitute diet is thus as highly palatable as natural pollen and easily provided as patties to colonies in standard hives. The possibility of improving the efficiency of beekeeping by providing nutritious feed lies, in part, in the development of an effective pollen substitute to feed the colonies when pollen is scarce [8,9]. The effect of supplementary feed means that locally available products are suitable as protein bee feeds. These products may be used by beekeepers to supplement the naturally collected pollen coming through the bee hive entrance to increase the palatability of the given feed [10].Supplementary feeding is vital for honey bees, as they need pollen and nectar sources to survive in nature. In particular, having young bees in colonies is vital before wintering, and proper feeding is necessary to achieve more production and a high population during the active season. The effect of feeding with pollen sources of different protein content on colony performance, wintering ability, and in-vitro longevity of colonies that

weakened after feeding with pine honey in autumn, or that needed to enter the winter period, was investigated [33].

The health, longevity, and development of honey bee colonies depend on the availability and quality of nutrients in the hive. Bees need sources of nectar and pollen that consist of carbohydrates, proteins, lipids, and micronutrients, necessary for survival, reproduction, and stress tolerance. Basically, honey bees are provided with all other nutrients, including carbohydrates, from nectar and protein from pollen. The pollen preference of colonies can vary depending on the protein content of the given feed. Bees prefer floral sources with high nutritional content. This affects the colony development [10, 31].

Supplementary feeding of pollen and honey is used to prevent hunger and to develop a higher population in bee colonies in summer, brood formation in starting of rainy season, and the beginning of the active season in the young worker bee population, and ready queen and drone breeding, to have healthier colonies [10,30]. During the year cause significant reductions in floral resources when the natural flora is insufficient, the decrease in the egg-laying level of the queen bee leads to a decrease in the population level in the colony. Malnutrition reduces the survival rate of individuals, causes the end of their life in the larval stage, makes the colony susceptible to disease, and causes individuals to leave the colony [3]. The effect of feeding with pollen sources of different protein content on colony performance, egg laying ability, and the strength of the colonies after feeding with protein source feeds was important [19,27].

Naturally-collected pollen is the best source of protein for honey bee nutritional requirements, but this pollen can vary in protein according to the floral source. Protein levels vary from 6% to 40%; the minimum protein level required for honey bees is 20% [18].

Dietary problems have been one of several factors linked to declines in honeybee health and populations. Honeybees, like any other animal, have specific nutritional requirements. Necessary proteins, carbohydrates, fats, vitamins, and minerals are available in their natural foods, which are pollen and nectar. Absence, shortage, or even poor quality of pollen results in stunted growth, inferior weight gain of young bees, reduced longevity, and poor development of hypopharyngeal glands, leading to insufficient royal jelly production to support normal growth and development of larvae, and normal egg production by the queen. These effects can result in poor colony development and production [2,12].

During the shortage or complete absence of pollen (particularly early in the season), or in the presence of only poor-quality pollen, beekeepers often feed colonies of honeybees with either pollen substitute (with no pollen) or supplement (with pollen). Ideally, these are materials that provide the required nutrients to the bees. There are disadvantages to pollen feeding. Beekeepers often do not collect pollen to add to diets, and commercially available pollen is costly. Furthermore, it may be contaminated with various honeybee pathogens. Ideal pollen substitutes would be readily accepted by honeybees year-round, healthful, rich enough to meet all their nutritional requirements, and inexpensive. To develop such ideal diets has been one of the most enduring apicultural research problems [2,38].

Honey bee nutrition has become a subject of interest due to its importance for colony development and productivity [24]. Bees collect nectar and pollen from flowers. Through enzymatic reactions, they transform sugar and proteins from the collected food into honey and beebread. Using these strategies, bees attempt to maintain a balanced diet, essential for good performance and health. Among the collected resources, pollen is the main source of proteins and lipids. It is needed for brood rearing and for the satisfactory development of adult bees [14,16,17,28]. The objective of this study was to evaluate the effects of supplemental feeding on honey bee colonies, to evaluate the effect of the supplementary feed on colony strength and honey yield and to determine the best cost supplement for the honeybees.

II. Materials And Methods

A. Study Area Description

The experiment was conducted in the Gazgibilla Research Apiary Site, Highland area of Wag Himra during the years 2020 and 2023. Gazgibilla is a district (Woreda) located in the Amhara Region of Ethiopia, specifically within the Wag-Himra Zone [37]. The area is characterized by a range of altitudes, including highlands. This variation in elevation affects the local climate and agricultural practices. Climate the district experiences a range of climatic conditions due to its varied topography. The average annual rainfall varies from 350 to 650 mm, and the temperature ranges from 18 to 35°C. The main rainy season typically occurs from June to September. Farmers in the district cultivate a variety of crops and engage in livestock rearing [9]. Sekota district is located 720 km away from Addis Ababa and 430km from Bahir Dar, the capital city of the Amhara Region at an altitude of 2200 m.a.s.l and at 12o 41' 11.92" N and 39°00' 58" E. Annual rainfall ranges between 350 - 700 mm, falling mainly from July to September. The pattern and distribution of the rainfall is erratic and uneven. Average temperature ranges from 16-27oC [11,23,36].

Beekeeping is also a significant activity in the districts, with the local honeybee race A.m. monticolla contributing to honey production. This is an important source of income for many households. Environmental Concerns: Soil erosion and deforestation are environmental issues that can affect apiculture productivity [24]. The experiment was started six weeks prior to flowering period finished during the availability of the natural pollen and nectar bee plants in the areas, specifically starting from at the mid of May to the start of July.

The colonies were kept in a standard frame hive and randomly assigned to one control and three experimental feeding groups with four replications.

B. Equalization of Experimental Colonies

Equalization of Experimental Colonies: before initiating the trials, experimental colonies were standardized by providing each with equal areas of capped brood, frames of honey, empty drawn combs and an equal weight of bees to ensure uniform colony strength across treatments.

C. Collecting Pollen

Bee-collected pollen was obtained during the first experimental season using a pollen trap with an efficiency of

16%. The collected pollen was stored in air-tight containers and stored in a freezer until further use.

D. Ingredients

Pea flour and acacia pod were used as the primary ingredients of the dietary Sugar syrup was added to enhance palatability and to maintain their consistency over extended periods. In addition, the 10% pollen was added into the supplement to improve acceptance by the bees, and small quantities of vegetable oil were included to increase the palatability.

E. Preparations of Patties

Dry ingredients were mixed thoroughly with a heavy syrup of 3 parts sugar to 1part of water, and then, after, 2 parts of syrup to 4 parts of dry mix, which was slowly added while kneading, and left for an hour overnight, and kneaded again before flattening into a 10 mm thick cake. Then cut into squares weighing about 200 grams, pack the cake and store in dry boxes. Bee-collected pollen pellets were first dissolved in water the final product was prepared dough like consistency.

Fig. 1. Photos taken during the feed preparation phase and feeding

Fig. 2. During feeding

Fig. 3. Internal colony inspection and colony performance after feeding

F. Treatments

T 1: Acacia pod flour: pollen (9:1 w/w)

T 2: pea flour: pollen (9:1 w/w)

T3: Acacia pod flour (2 parts), Pea flour (3 parts) (pollen (9:1 w/w)

T4: Colony (Not supplemented)

In each case, 4 parts of the dry mix were added to 2 parts of heavy sugar syrup, 10% of bee collected pollen to increase palatability, and sufficient water was added to substitute the diet mix to form dough like consistency. The experiment was conducted under two phases:

Observation Phase: - under this phase, the palatability of the feeds was tasted, and it was conducted at first year before the actual experiment.

Actual Experimentations: - Those treatments with better intake during the palatability test were assigned for the experiment.

G. Installation of Patties

The patties were given inside the hive in division-board feeder, which was in proximity to the unsealed larvae in brood combs where nurse bees have been ready to access it. Feeding was started 6 weeks before the flowering of the natural pollen and nectar source plants. 200 grams of prepared feed was provided for all experimental colonies every week.

H. Parameters to be Measured

The colony establishment rate: - ratio of a particular hive type colonized by bees from the total number set up in the experiment, in percentage.

1) Population Dynamics: - The population was measured using the Liebefelder method, mainly based on the assumption that a 10 cm x 10 cm unit area holds about 125 bees and 400 brood. A frame 20 x 40 cm be divided into 8-unit areas on one side (10cm x10cm). Thus, two sides of a frame have been 8 x 2 = 16-unit areas.

2) Honey yield measure: - It was recorded every harvesting season by weighing frames expressed in Kg/colony/year.

3) Economic Analyses of the diet: - The cost-related data was recorded and evaluated at the end of the experiment.

4) Experimental Design: - Using a Complete Randomized Design (CRD) with four replications.

III. Data Analysis

Treatment effects on brood, pollen, and nectar area attributes were evaluated using one-way ANOVA, and means were separated using the Tukey Honest Significant Difference test (TSD test). Food consumption rate, bee population strength, and honey production were assessed using descriptive statistics.

IV. Results And Discussion

A. Abbreviations and Acronyms

The efficacy of three pollen supplement diets was investigated in honey bee, A. mellifera monticolla colonies to

determine diet consumption rate, as well as their effect on worker brood area, pollen area, nectar area, adult bee population, and on honey yield. The mean consumption rate of each feeding type used during the dearth period is indicated in (Figure 1,2 and 3). During the first two months of the dry season (May-June), the consumption rate of each feed type was observed to be slightly increasing. Similar trends were detected during the rainy season (July) as they were during the dry season (Figure 1). However, because of the availability of natural pollen in the field from the end of July to the first week of August, pollen supplement diet consumption was gradually decreased. Before the flowering period, honeybee colonies were attracted and preferred to ingest the mixture of acacia with pea over sole acacia and pea.

During the study period, the consumption rate of the diet mixture of acacia with pea was recorded as the first ranking order among all treatments. Treatment 3 (A mixture of Acacia and Pea), resulted in a complete patty consumption of 243.19g. In comparison, Treatment 2(sole pea) and Treatment 4(sole acacia) recorded consumption of only 135.73g and 138.5g, respectively (TABLE 4). Supplementation with a mixture of Acacia with Pea significantly increased colony weight gain and honey yield in honeybee colonies. These results clearly indicated that honey bees respond more to a mixture of acacia and pea cakes with maximum feed consumption than to other alternative supplementary feeds.

The current finding was consistent with those [33]. It has been reported that feeding honey bees with pea flour, which has a high protein content, causes an increase in the brood area, the number of frames covered by bees, and honey yield. And also [32], reported that soybean was more palatable and consumed by honeybees than other feedings, particularly when natural pollen supplies were scarce or unavailable in the field. Overall, the consumption of a mixture of acacia with pea diets was superior in comparison with the sole acacia, Sole pea, and the control (F) ($P < 0.05$). T1(sole acacia) and T2(sole Pea) were not significantly different from each other but were significantly different from the control (TABLE 1).

The number of frames and brood area were significantly higher in treatment 3(mixture of acacia with Pea) than those of other treatments (TABLE 1). The highest number of frames (17±1.56) was found at the end of August after the supplementary feedings had finished. The result of the number of frames (bee population) was similar to the findings of [10,21]. Treatment 3 showed the highest sealed brood area compared to other colonies. The reason for this result could be explained by a relatively higher feed consumption rate.

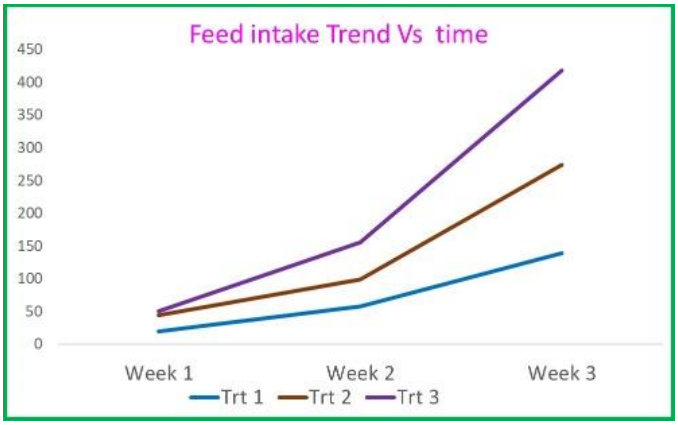


Fig. 4. Pollen supplement diet consumption rate in grams

The reason for the lowest honey yield and colony weight in terms of adult bees, open brood, and sealed brood in treatments 1, 2, and control could be explained by the different flavors of supplementary feedings used in the study. The number of frames and brood areas was significantly higher in treatment 3 than that of other treatments (TABLE 1). The highest number of frames (bee population occupied) (10.87±1.25), (6.32±1.85), (5.89±1.95), and (3.89±1.66) for treatment 3, treatment 2, treatment 1, and the control, respectively, was found in October during the honey harvesting season. The result of the number of frames (bee population) was similar to the findings of 27.53 [6]. The average number of frames with bees was counted by mung bean (6.66), the control (unfed) 3.28 in experimental colonies [17]. This study is comparable with the results of [34],Who recorded an overall average of 9.7±2.6 frames of bees fed on pea flour. [35] reported that the number of bees covered on frames is positively affected by feeding a protein-rich diet to bees.

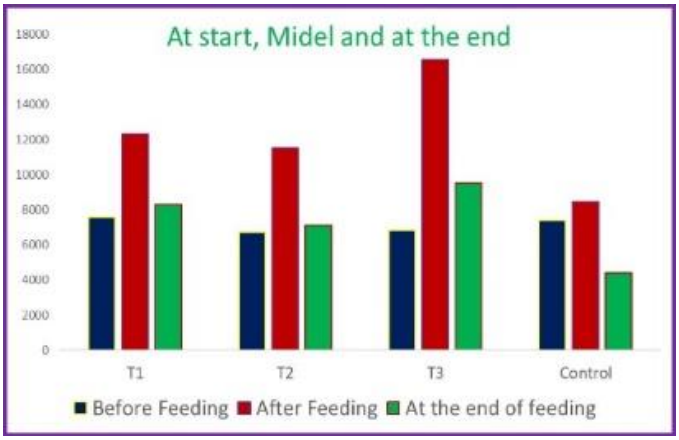
Treatment 3 showed the highest sealed and open brood area compared to the other experimental colonies. The reason for this result could be explained by the general scarcity of protein source feeds in the field during the dry season.

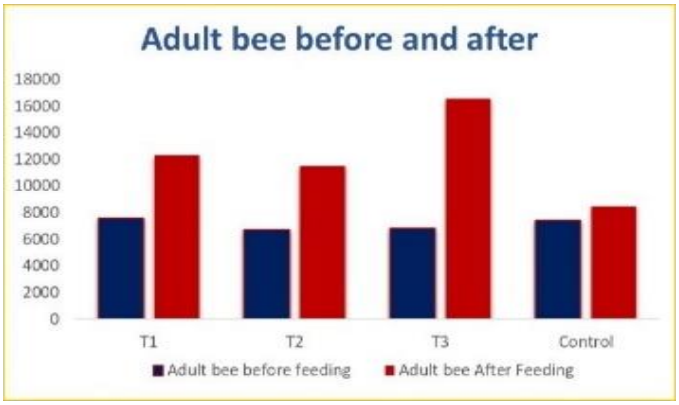
B. Effect of Pollen Source Supplement Diets on Sealed and Open Brood Areas

The results in TABLE 1 confirmed that there were extremely significant variations in brood rearing activities among all treated colonies with evaluated pollen source supplements and control colonies. The results clearly indicated that colonies fed a diet of a mixture of acacia and pea produced the highest rate of both sealed and open worker brood, with a mean of 224.0±19 cm2 /colony, followed by the diets of pea, acacia, and the control, with a mean of 188.0±22, 172±17, and 94±5.5 cm2 /colony, respectively. The control group had the lowest brood rearing rate, with a mean of 94± 5.5 cm2 /colony. The current finding was consistent with [28,29], who reported that soybean products were a suitable substitute as a pollen supplement and had a positive effect on brood rearing activities. In addition, the results obtained by [3,6]. Feeding soybean flour alone or in combination with other flour indicates that it has great potential for enhancing colony maintenance and brood rearing during a pollen shortage. Furthermore, [29,31]. They also reported that honeybees increased the surface of the sealed brood area after

consuming various pollen- supplemental diets. Similarly, [15] found that sealed brood area increased in supplementary-fed bee colonies compared to unfed bee colonies(Graph 1).

C. All Population Estimation in Terms of AB, SB, AND OB)





Graph 1. Colony performance before and after feeding AB = adult bee, OB = open brood and SB = sealed brood

D. Effect of Pollen Supplement Diets on Storage of Bee Bread and Nectar

The data tabulated in (Table I) showed highly significant differences in pollen storage between all experimental colonies with tested diets and control colonies. Accordingly, colonies fed a diet with a mixture of acacia and pea significantly produced the highest rate of nectar storage with a mean of 152.8±18.72 cm2 /colony, followed by the pea and acacia diets with means of 90.3±16 and 72.9±21 cm2 /colony, respectively. The lowest pollen storage rate was recorded for unfed control colonies with a mean of 51.3±1.07 cm2 /colony. The average nectar area on the frames was indicated in TABLE 1. The maximum nectar storage (152.8±18.72 cm2) was found on the frame that fed the acacia with pea mix cake, but control colonies stored less nectar with a mean of (51.3±1.07 cm2).

This finding revealed that there were significant differences in the average amount of pollen and nectar stored across all fed and unfed control colonies. The current finding was consistent with (38), who reported that feeding soy flour continuously increased pollen and nectar storage from the start of the experiment to the end, and stayed much greater than the control group. [28,29,37] also reported that after feeding a pollen supplement, the bee colonies' pollen hoarding capacity was better than the control. These findings imply that the colonies are constantly producing and rearing more brood, as well as foraging for extra pollen and nectar. Furthermore, [18,28] suggested that colonies maintained with pollen supplements during times of scarcity of natural pollen would be better able to rear more brood and collect surplus nectar early.

E. Effect of Pollen Supplement Diets on Honey Bee Strength

The average number of frames with bees is designated in Table I. Statistically significant ($p < 0.05$) variation between feed types was also observed in colonies without supplementary feeding. The highest frame with bees was counted by treatment 3 (acacia +pea) (10.687±1.25) as compared with the least, which is the unfed (3.89) colony. This study is higher than the result of [7,9,15], who recorded an overall average of 9.7±2.6 frames of bees fed on pea flour [35] reported that the number of bees covered on frames is positively affected by feeding a protein-rich diet to bees.

The effect of pollen supplement feeding on the number of worker bees covered by the bee frames was observed and recorded. The result showed that, regardless of various feeding periods, the colonies fed the mix of acacia with pea had the highest number of frames covered by bees (10.89), which was statistically significant from all other treatments. Colonies given a diet of sole pea and sole acacia had 6.32 and 5. 89 number of frames covered by worker bees, respectively (TABLE 1). There was no significant difference in the number of frames covered by bees for the diet acacia and diet pea, while the control colonies had the lowest value (3.89). The result was consistent with the findings of [20,31,33].who observed that supplement diets produced more honeybee frames in comparison to non-supplemented control colonies. [32,34]. Also reported that the number of bees covered by frames is positively affected by feeding a protein-rich diet to the bees. [31] found that, as compared to other bee feeding materials, pea, chickpea, and soybean flour are comparatively high in protein and locally available and are preferred as pollen supplement diets.

Generally, honeybee colonies fed with supplemental feeding at different periods produced significantly more worker bees than unfed control colonies(Table I).

TABLE I. IMPACT OF POLLEN DIETS ON HONEYBEE COLONIES

Fed type	Acacia (Mean ± SD)	Pea (Mean ± SD)	Acacia +Pea (Mean ± SD)	Unfed (Mean ± SD)	LSD	p-value
No of Frame with bees	5.89±1.9 [b]	6.3±1.9 [b]	10.87±1.3[a]	3.9±1.6 [c]	2.065	0.021
Brood area on frame (cm2)	172.0±2[a] [b]	188±2[ab]	224.0±2[a]	94±5.5[c]	38.23	0.044
Pollen area on frame (cm2)	64.3±1[b]	97±24[b]	120.9±26.5 [a]	83.7[b]	22.02	0.039
Nectar area on	72.9±2[b]	90.3±2[b]	152.8±18.7 [a]	51±1.1[c]	10.4	0.015

frame (cm2)						
Hone y area on frame (cm2)	104.1±1[b]	94±3.[1b]	232±16.1[a]	80.2[b]	13.5	0.03 7

F. Effect of Pollen Supplement Diets on Honey Production

Honey yield per colony was analyzed following the consumption of various diets. Compared to the colonies receiving the mixture of acacia with pea diet produced the maximum honey yield (35 kg per colony), followed by that fed acacia alone (15 kg) and pea alone (8 kg) while unfed control colonies produced no honey (0 kg per colony) (Table II). The current finding are consistent with those of [29], who reported that colonies fed a diet of soybeans generated considerably more honey than unfed control colonies. According to [29,9,28]. Colonies fed an artificial diet produced more honey yield than unfed controls. The study [27] also reported that providing a pollen supplemental diet for honeybee colonies during a dearth period increased honey yield in the succeeding honey flow season. Reference [4], recommends maintaining healthy colonies before nectar flow for higher honey production, as the strength of worker bees in a honeybee colony before the honey flow season is the most important factors influencing honey production. Moreover, [29,4], reported that higher consumption of pollen supplemental diet leads to higher production of brood and more populous colonies, which in turn produce more honey.

Treatment 3 consumed relatively more of their patty, 243.19 g, whereas treatment 1 consumed only 138.59 g and treatment 2 consumed only 135.73g. The mixtures of acacia pod flour and pea flour (2:3) and 10% of pollen supplements significantly increased weight gain and honey yield on experimental colonies. These results clearly indicate that honey bees respond more to a mixture of acacia with pea and 10% pollen cakes with maximum feed consumption than to other alternative supplementary foods (Table III).

TABLE II. THE FEED CONSUMPTION AND THE HIVE RESOURCES CHANGE

Treatments	Adult bee population	Harvestable Honey yield /kg
Acacia	10313	15[b]
Pea	11508	8[c]
Acacia +Pea	16555	35[a]
Control	7469	5[c]

When the natural flora is insufficient, the decrease in the egg-laying level of the queen bee leads to a decrease in the population level in the colony. Malnutrition reduces the survival rate of individuals, causes the end of their life in the larval stage, makes the colony susceptible to disease, and causes individuals to leave the colony. Feed Consumption (feed intake): The mean feed consumption (g/colony) of Treatment 3 was significantly higher than that of Treatment 1, Treatment 2, and the control however, both treatments (Treatment 1 and 2) differed significantly from the control ($P<0.05$).

TABLE III. FEED CONSUMPTION (FEED INTAKE)

Treatments	Mean
Acacia (treatment 1)	138.59[b]
Pea (treatment 2)	135.73[b]
Acacia +Pea (treatment 3)	243.19[a]
Control (un supplement)	0.00[c]

TABLE IV. COST AND NET BENEFIT ANALYSIS OF FEEDS ACROSS TREATMENTS

Treatments	Honey yield	Current price of honey (400 birr)	Production cost	Net benefit
Acacia	15	6000	22	5978
Pea	5	2000	54	1946
Acacia + Pea	23	9200	41	9159
Control	_	_	_	_

In addition to this, the net benefit of treatment three is higher than that of treatment one, treatment two, and the control, 9159, 5978, 1946, and 0, respectively. Due to this result, the higher the net return is for treatment three(Table IV).

V. CONCLUSIONS

It can be concluded that a pollen supplement diet should be supplied to bee colonies during dearth periods so that the strength of bee colonies can be maintained for the next honey flow season. Thus, the results obtained suggest that the diet mixture of acacia and pea was found highly useful for attaining maximum bee strength and honey production. Therefore, the author recommends the large-scale utilization of a diet mixture of acacia and pea for the sustained reproduction and buildup of honeybee colonies during the dearth periods (6 weeks before the active season). It is concluded that a mixture of acacia and pea patties could be recommended as supplementary feed to boost the bee population and to get high honey yield during the six weeks before the active flowering period.

VI. RECOMMENDATIONS

It is recommended that a mixture of acacia with pea in the ratio of (2:3) and 10% of pollen patties could be as supplementary feed during the scarcity period to boost honey bee colonies and to get the optimum honey yield strong colonies in the study area.

ACKNOWLEDGMENT

The author would like to express a deep appreciation to Sekota Dry Land Research Center(SDARC), as well as the Amhara Agricultural Research Institute (ARARI) for financial support for the research.

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