Saudi Journal of Biological Sciences 28 (2021) 6861–6868

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Original article

Nutritional effects of supplementary diets on brood development, biological activities and honey production of *Apis mellifera* L

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ARTICLE INFO

Article history:
Received 31 May 2021
Revised 22 July 2021
Accepted 24 July 2021
Available online 30 July 2021

Keywords:
Honey bee colonies
Diets
Palatable
Profit
Bee strength
Brood area

ABSTRACT

The present research work was conducted to assess the impact of nutrient-enriched diet on the physiological activities and subsequently honey yield. Eighteen colonies of *Apis mellifera* L. were selected from Dera Ismail Khan region, KPK, Pakistan, during the winter and summer seasons, 2019–2020. Five pollen supplement diets were prepared and provided to screen out the palatable one to be fed as pollen alternative nutrition to bee bread. Results of diet consumption regarding mean data for consumption rate displayed that soybean flour enriched artificial diet was maximally consumed (74.34 g) by honey bees per week. Minimum consumption was observed for grinded groundnut enriched diet (64.62 g) which was relatively lesser than the other tested artificial diets. Results of area of worker brood disclosed that soybean flour fortified diet (1489.27 cm^2/colony) statistically noteworthy than the other artificial diets whereas control (463.51 cm^2/colony) was least effective. Highest bee strength (10.00 bee frames/colony) was noted in the bee colonies fed with soybean flour fortified diet, date paste (8.0 bee frames/colony) was the next effective one, among the tested pollen replacement diets whereas relatively least (5 bee frames/colony) was noticed in case of grinded groundnut. Highest body weight (12.41 g) of neonate bees was noted in case of soybean enriched diet while lowermost (5.31 g) was noted in control bees. Results of wax cell built up and foraging efficiency were also superior in artificial diets than respective control bees. Hence, artificial diets especially soybean-enriched pollen alternative diet can boost up the physiology of honey bee leading to increased honey yield and profit.

1. Introduction

Pollen complementary diets play a significant part in honey bee health as well as honey production. For the purpose of brood development, honey bees needs pollen and nectar to encourage foraging flights (De Grandi-Hoffman et al., 2008). Pollen provides fats, minerals, vitamins, and proteins for brood raising whereas nectar delivers carbohydrates (Brodschneider et al., 2010). Good quality dietary substances are important for successful production of bee colonies (Al-Ghamdi et al., 2011). In deficiency of natural pollen sources synthetic pollen enriched nutrition can complement honey bee broods (Matilla and Otis, 2006) which is important for young bee's reproduction, brood development and conservation of bee colony (Manning, 2001) and honey production (Saffari et al., 2010). In Pakistan, during lien periods (June-July) when natural pollen provisions are not adequate to support colony health and development, apiarists frequently nourish honey bee colonies with pollen enriched artificial diets like gram flour, maize and defatted soybean (Safari et al., 2006). Sugar syrup as additional nursing is also practiced by many of the apiarists to speed up brood development and oviposition (Usha et al., 2014). Inadequate diet sources harmfully affect the ability of bee colony. Colonies are liable to be attacked by different types of pathogens and pests such as mites (*Tropilaelapes clareae* and *Varroa destructor*), birds, bee eating, hornets and black ants etc. owing to deprived colony strength (Aziz et al., 2015). These aspects result in waning and occasionally fading of honey bee colonies. Hence, utmost attention must be taken in the management of bee colonies.

To cope up this situation numerous investigators formulated and tried different synthetic nourishments (Saffari et al., 2010). Pande and Karnatak (2014) checked the impact of 4 diverse pollen alternative diets viz., ger pea, ger chickpea, ger mung bean and ger horse gram which were equated with control. They noted >65%

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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2021.07.067
1319-562X/

palatability and gradually upsurge in foraging activity, pollen stores and brood area afterward feeding in blend of all the tried diets (Gemeda, 2014). Moreover, it was also noticed that every tested artificial diets was expressively superior over control. Usha et al. (2014) executed research work by providing flours of soybean, wheat, maize and gram as pollen replacements for *A. mellifera* broods. They blended flour + honey + water with the every selected four in the research trial. They observed that blend with soybean flour blend flour + honey + water was the excellent pollen alternative among the all four blends and bee population was also augmented afterward nourishing diets. Aly et al. (2014) compared the effectiveness of flour of cumin, fenugreek, fennel, coriander, grams, rice, peas, beans, oats and white kidney beans with rock sugar (control). Their research results show that the highest colony count per week recorded in Diet 1 is 47.42 g (oatmeal 50% + rice flour 25% + fennel seed powder 25% + honey). Rezaei et al. (2015) checked the dietary effects of soybean meal and fermented gluten meal as complementary nourishments for colony activities while sugary material and pollens were used as control for comparison. They noticed noteworthy variations in diet consumption and brooding activities between the control group and pollen enhancement nutrition ($P < 0.05$). Amro et al. (2016) supplied 5 supplemental foods such as feedbee, soybeans, pod powder, date powder, corn gluten and equated with control bees colonies to determine the impact of bees on colony feeding activities and nutrition intake. They observed maximum intake of date powder (213.2 g/colony), feedbee was the next effective one (173.6 g/colony), pod powder (124.1 g/colony) and corn gluten (95.7 g/colony), soybean meal (87.4 g/colony). They further pointed out that the largest worker breeding colony recorded by the control group was 1066.7 cells/colony, followed by 174.7 sealed breeding cells/colony by date powder.

In Pakistan, little work has been done on the effects of pollen-replacement foods on *A. mellifera* L. colonies. Rashid et al. (2013) described that bee colonies fed with a gram enriched food resulted in augmented honey yield compared to bee colonies fed with corn meal, pollen and brewer's yeast. Therefore, it is recommended that a diet supplemented with pollen can be an excellent pollen alternative diet for brood development. Sabir et al. (2000) described that corn meal + vitamin B complex + glycine were the highly accepted diets for bees and the brood area noted by bee feeding with this diet blend is 416.14 square inches. It is essential to provide pollen alternates to bee colonies to maintain subsistence and development (Kumar et al., 2013), which can be calculated by diet consumption or measurement of workers' brooding area (Sihag and Gupta, 2013; Kumar and Agrawal, 2013; Pande et al., 2015; Shehata, 2016; Okuyan and Akyol, 2018). Aly et al. (2019) studied the impact of artificial diet on honey bee colony strength and found soybean diet as the most effective. Similarly, Islam et al. (2020) also found soybean enriched diet improved the different morphological, physical activities and ultimately honey yield. Kumar et al. (2021) noted augmented honey yield and disease resilience in honey bees reared on artificial diets. Taking the above factors into consideration, the purpose of this study is to formulate and test a preparation from a nearby accessible protein source, which is preferably delicious to honeybees, and to determine its nutritional effect on *A. mellifera* colony growth and honey production.

2. Materials and methods

2.1. Study site

This study was carried out at the Faculty of Agriculture, Gomal University, Dera Ismail Khan. KPK, Pakistan. Locally acquired colonies of *Apis mellifera* L. were used for field study regarding honey bee artificial diets.

2.2. Experimental colonies

Eighteen colonies of *A. mellifera* L. were selected from Dera Ismail Khan, Pakistan, in winter and summer period, 2019–2020. *A. mellifera* L. colonies were of about equal strength consisting five bee covered combs for this experiment. Honey bee colonies were divided into six groups of equal size; five groups were used to study the effect of pollen substitute's diet on the honey bee biological activities and sixth one as control.

2.3. Preparation of different pollen substitute proteinaceous diets

Five pollen substitute diets were prepared and supplied to select the palatable one to supply as pollen substitute diet to bee bread or pollen (the main source of protein for bees) Table 1. These five pollen substitute diets were made of five locally available ingredients. These five diets were prepared by mixing below mentioned ingredients in different amounts. The main component in first diet combination were soybean flour (traditional pollen substitute), sugar cane syrup in diet 2 (as a main protein and carbohydrates), date paste in diet 3 (easily available and economical carbohydrates source), black gram flour in diet 4, and grinded ground nuts in diet 5 (rich source of protein).

Colonies groups were supplied with single chosen diet during the study duration. Each colony was supplied with 100 g of the specific diet in plastic wrapping with multiple cuts on each side at 15-days interval. Sugar syrup (250 mL, 1:1, w/v) was supplied as supplementary feed to each colony at interval of 3 days for activity stimulation. Each colony was also provided with a separate water source.

2.4. Patty feeding

The diet patties were wrapped and multiple cuts were made on each side of the plastic wrapping and were placed in the colony. They were readily and easily available to the honey bee colonies. The patties were checked at 5 days interval and were replaced with freshly prepared patties at fifteen days interval.

2.5. Diet consumption

The amount of food consumed was determined by subtracting the weight of the fresh diet patty and the weight of 15 days old patty after being placed in the colony (g/colony). The data obtained were recorded at 5 days interval for each formulated diet. The total amount of patty consumed of each diet type during the experiment period was also being recorded by procedure as described by Amro et al. (2016).

2.6. Brood area measurement

The sealed brood area of worker bees was measured afterward fourteen days by means of computing frame having wire net with scaling giving an area of 1 square inch each and then changed into cm^2 by multiplying with 2.54 as described by Abd El-Halim et al. (2006). This closed brood was referred as standard for adjudicating the growth of colonies.

2.7. Foraging effort

Foraging effort was assessed each 21 days from May to September 2019–2020. The entry of every hive was filmed for sixty seconds to record the number of honey bees coming back to the

Table 1
Diets for honey bee colony.

Diet		Skimmed Milk	Sugar	Honey	Glucose
Diet-1	Soybean Flour 30%	25 %	5%	20%	20%
Diet-2	Sugarcane syrup 30%	25 %	5 %	20 %	20 %
Diet-3	Date Paste 30 %	25 %	5 %	20 %	20 %
Diet-4	Black gram flour 30 %	25 %	5 %	20 %	20 %
Diet-5	Grinded groundnut 30%	25 %	5 %	20 %	20 %

hive with and deprived of corbicular pollen masses. Lengthier surveillance periods would have supplemented activity inconsistency owing to period of day. Proportion of bees fetching back pollen to the colony was then computed. The records were continually made earlier to opening the hives and between 10 AM and 14 PM to optimize the foraging action and reduce alterations owing to day time (Delaplane et al., 2013).

2.8. Measurement of thorax weight and number of wax cells built

For this purpose, bees were sliced up into three insect body parts and were combined into ten groups. Mean thorax weight was assessed by dehydrating to a persistent temperature (60 °C for period of 48 h) and with precision of 0.1 mg (Sagili et al., 2005). Moreover, the number of wax cells built in every group was documented.

2.9. Determination of dimensions of queen cells

Queen cells were created by the Doolittle's technique (Johansson & Johansson, 1973). From the entire number of queen cells, ten from every group were practiced to measure their sizes (width, length and opening diameter) and the body weight of the freshly developed queens. The width and length of the ten randomly selected queen cells were measured earlier queen appearance. Measurement of queen cells length was done from the origin of the beeswax cell cap to the uppermost point of the cell, whereas their width was measured at the broadest point. Quickly afterward queen appearance, the subsequent qualitative characteristics were measured: the weight of freshly developed queens (on appearance) and the queen cell opening diameter. All queen cells measurements were accomplished with a digital fractional calliper with the accuracy of 0.01 mm (Dolasevic et al., 2019).

2.10. Honey production

After completion of the research, results on honey production were noted to compare honey production of bee colonies fed with artificially prepared nourishments with control bee colonies to check the effects of pollen substitutes supplied to bees in this research work (Aziz et al., 2015).

2.11. Expenditure

The cost analysis was calculated on the basis of prices of various ingredients of the artificial diet formulations.

2.12. Statistical analysis of data

Analysis was executed by a two factor factorial under Completely Randomized Design (CRD) along with triplicates. Statistical analysis of frames covered with bees, sealed worker brood area, diet consumption and honey yield/colony was carried out by two ways Analysis of Variance (ANOVA) using statistics software version 8.1. Treatment means were separated through Least Significant Difference (LSD) at $p \leq 0.05$. Results of dimensions and other qualitative parameters were processed by F test, and the differences between groups assessed with Duncan's Multiple Range Test (a ¼ 0.05).

3. Results

The current research work was executed to check the effectiveness of some pollen alternative diets on the health and routine activities of the honey bees. Impacts of 5 formulated pollen alternate diets were determined in *A. mellifera* colonies for frames covered with bees, their impact on worker brood area, diet consumption rate and honey yield (Figs. 1, 2, 3 and 4) and the data are described underneath;

3.1. Diet consumption rate

Results revealed that soybean fortified meal was highly consumed (74.34 g) by honey bees in seven days trailed by date enriched food with the mean intake value of 64.23 g/7-days (Fig. 1). The values of formulated foods consumption for sugarcane syrup and black gram fortified diets were 57.43 g and 48.12 g/bee colony, respectively. Lowest consumption was noted for grinded groundnut (64.62 g) which was statistically less than the entire fed diets in the current research work. Noteworthy variations were observed in the mean diet consumption in entire examined honey bee colonies ($P < 0.05$). It is explicit from seven days diets consumption results of the formulated diets that in the months of June and July when there was scarcity of natural pollen for honey bees in the surroundings, augmented consumption rate of the pollen alternate foods was noted. However, owing to accessibility of natural pollen to honey bees afterward 2nd week of July, the consumption rates of pollen alternate foods was slowly reduced.

3.2. Worker brood area

Worker sealed brood area was observed afterward intervals of fourteen days in bee colonies nourished with pollen alternate foods (Fig. 2). Early area of worker brood in entire selected bee colonies was 397.52 cm^2. The results revealed that bee colonies fed by pollen alternate foods initiated the worker brood rearing. Highest worker sealed brood area was noted in Diet-2 trailed by other rest of the diets. This tendency sustained up to the last week of August. There was an explicit sign of growing worker brood area in $1\text{–}1/_2$ month of consumption of formulated foods tested in this research work. Overall results disclosed that from the onward of 2nd week of July, augmented area of worker brood was noted in entire the bee colonies studied in this research trial. Highest worker brood area was noted in Diet-1 (1489.27 cm^2/colony) statistically different from Diet-3 (1346.6 cm^2 per colony), Diet-2 (1157.4 cm^2 per colony), Diet-4 values being 1056.2, Diet-5 (790.31 cm^2 per colony). Control (463.51 cm^2/colony) was the least effective. Bee colonies fed by diverse pollen alternate foods were statistically different from each other and superior to bee colonies in respective controls.

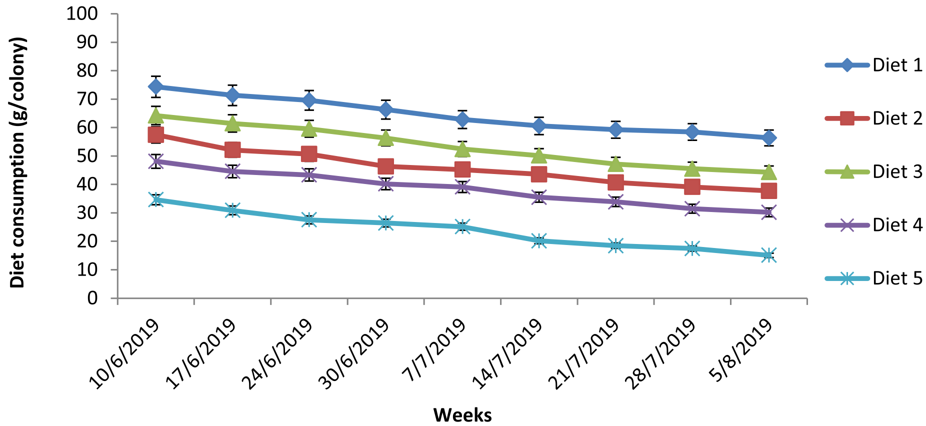

Fig. 1. Pollen substitute diet consumption (g/colony).

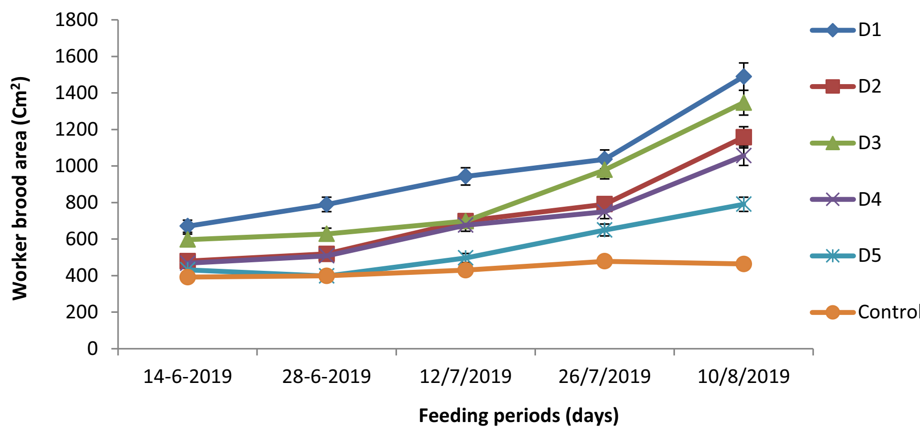

Fig. 2. Effects of pollen substitute diets on worker brood area (cm^2/colony).

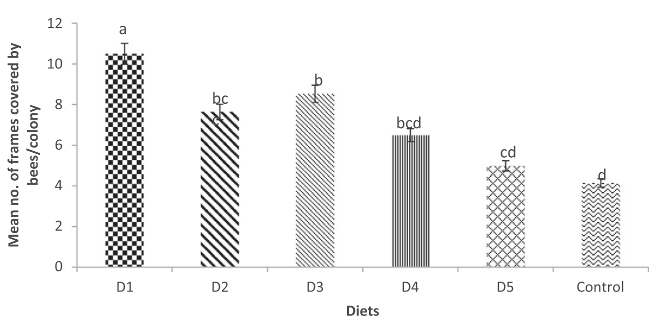

Fig. 3. Average number of frames covered with bees/colony.

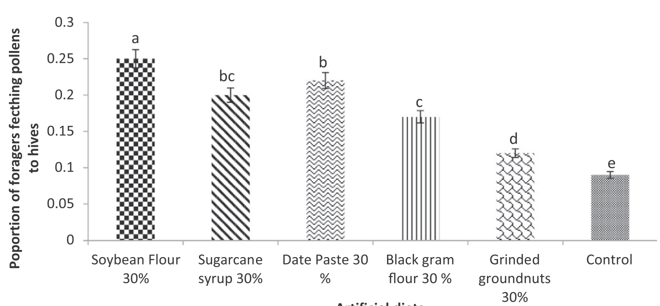

Fig. 4. Proportion of forager bees depending of artificial diets.

3.3. Honey bee strength

Data presented effects of pollen alternate foods on hives concealed with bees in the month of August (Fig. 3). The data revealed that highest (10.00 bee frames/colony) bee strength was noted in the bee colonies supplied with soybean enriched diet, date fortified food (8.0 bee frames/colony) was the next effective one. Both the diets gave statistically different results compared to from those bee colonies fed by rest of the prepared foods and colonies in control. The numbers of bee frames were 7, 6, 5 per colony with sugarcane syrup, black gram solution and grinded groundnut diets, respectively. Bee colonies in control experimental units produced less number of frames/colony i.e. 4 frames/colony as compared to all the formulated diets in current research work.

3.4. Foraging effort

Proportion of foragers coming back the hive and impacts of prepared diets was found significant ($p < 0.05$). Data (Fig. 4) revealed that highest proportion of foragers (0.25) was noticed in soybean enriched diet followed by date paste (0.22), sugarcane syrup (0.20), black gram flour (0.17) while lowermost (0.12) was noted in grinded groundnut fed bees over control (0.09).

3.5. Biological actions

Results (Fig. 5) depicted that average number of queen cells, combs covered by bees, sealed brood cells and queen cups were

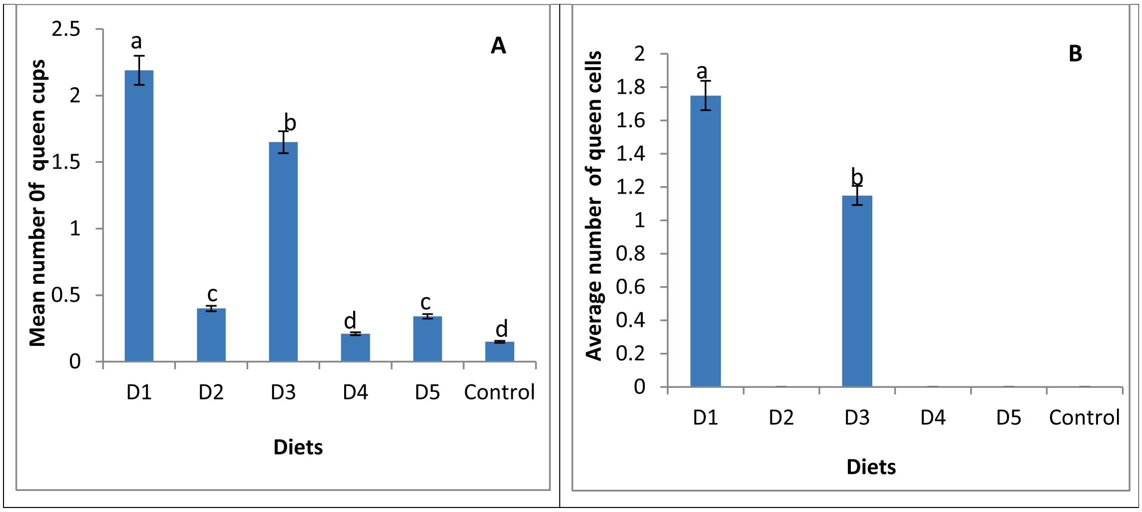

Fig. 5. Impacts of the pollen substitute diets on the dissimilar biological actions of honey bee. A) Mean number of queen cups, B) Average number of queen cells.

superior in soybean fortified diet while grinded groundnut diet proved less effective but better than control. In case of average of queen cells, D-2, D-4 and D-5 proved least effective as no queen cells was observed.

Moreover, there was an optimistic association that was extremely significant ($p < 0.003$) between the quantity of food used up and upsurge in brood area and alteration in adult population for the tested diets in the research (Table 2). Brood in colonies was influenced by quality of the diet as well.

3.6. Thorax weight

Diverse protein diets had noticeable impacts on the thorax weight of bees (Table 3). Normally, thorax weight of bees nourished on artificial diets was expressively greater compared to control. Maximum values of thorax weight (33.12 and 32.54 mg/bee) were noted in workers fed on soybean flour and date paste diets (deviations percent of 18.10% and 17.61%), respectively. While, the lowermost weight value (23.17 mg/bee) was computed in control bees.

3.7. Total number of wax cells built

The entire number of wax-built cells was considerably dissimilar between groups (Fig. 6). Generally, bees fed on diverse artificial diets resulted in expressively greater wax-built cells, whereas the number of the cells in control bees was remarkably less compared than the artificial diets.

3.8. Measurements of queen cells and body weight

Results (table 4) disclosed that queen cells from grinded groundnut fed bees had the minimum length and were expressively smaller compared to soybean and date paste fed bees. There were no significant differences in queen cell opening diameter and width between soybean flour and date paste fed bees. The maximum mean weight of newly emerged queen was in Soybean flour

Table 2
Linear regressions of the variation in honey bee brood area and size of the adult population in colonies nourished dissimilar supplemental diets over the study period.

Types of diet	Brood area			Adult population		
	Slope	T	P-value	Slope	T	P-value
Diet-1	0.298	7.81	<0.003	0.071	17.30	<0.003
Diet-2	0.087	3.97	<0.003	0.061	15.12	<0.003
Diet-3	0.0589	6.23	<0.003	0.237	9.87	<0.003
Diet-4	0.141	5.34	<0.003	0.072	7.56	<0.003
Diet-5	0.056	4.13	<0.003	0.101	5.26	<0.003

Table 3
Thorax weight (mg/honey bee) of 18 days old workers fed on different artificial diets and sugar solution only (control).

Age of bee	Bee thorax weight (mg) (Mean ± S.D.) Artificial diets					Control
18 days of age	Soybean Flour 30%	Sugar cane syrup 30%	Date Paste 30 %	Black gram flour 30 %	Grinded groundnuts 30%	
Deviation (%)	33.54 ± 0.61a 18.10	29.10 ± 0.70b 13.51	32.56 ± 0.45a 17.61	27.34 ± 0.92c 14.31	26.89 ± 0.75 cd 11.09	23.17 ± 0.41d –

Means having different lettering (between treatments) are statistically significant (means in identical row, p < 0.05), S.D = standard deviation

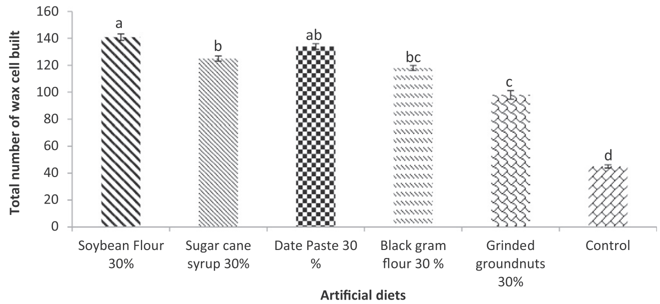

Fig. 6. Total number of wax cells built by workers fed on different artificial diets and sugar solution only (control) afterward twenty one days. Bars having different letters show significant differences (p < 0.05).

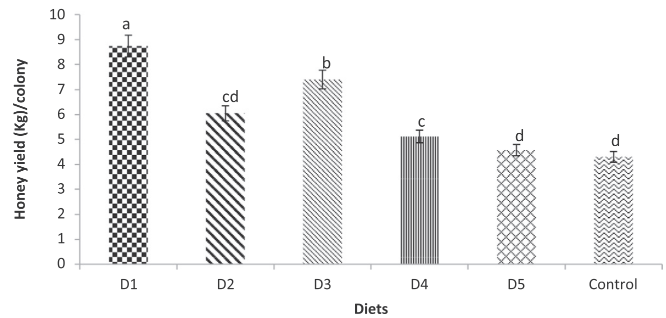

Fig. 7. Average yield of honey (kg/per colony).

fed bees and was significantly higher compared to the other diets. Table 5.

3.9. Highest honey yield

Yield of honey varied remarkable when the bee colonies nourished with pollen alternate foods. The deposited honey was collected and weighted afterward 48 days of delivered pollen alternate foods. It was noticed that healthy and strong bee colonies resulted in augmented honey yield compared to frail bee colonies. Highest number of frames roofed with bees and augmented honey yield was noted by colonies nourished with over soybean enriched diet which also had the maximum consumption rate of pollen alternate food than the other bee colonies studied in this research trial (Fig. 7). Highest honey yield i.e. 8.74 kg per colony was collected from soybean fortified diet fed bee colonies while the minimum (4.3 kg/colony) yield was extracted from the bee colonies in control colonies deprived of pollen alternate foods (Fig. 7). Other artificial diets showed intermediate results for honey production but superior to check bee colonies.

3.10. Gross returns

It was computed from the yield of honey produced in kg/bee colony nourished with pollen alternate food and marketplace price/kg of the honey in the month of October. Price of honey per kg in whole sale market was @ Rs. 1000. This market price/kg of honey was multiplied with honey yield (kg) and the amount in rupees was the gross return. Gross profit: Gross expenses were deducted from gross return to compute the gross profit (Table 2)

3.11. Economic analysis

Data (Table 6) presented amount and ingredients used in preparation of pollen alternate foods and honey yielded in bee colonies getting diverse pollen replacement foods. All the artificial diets were consumed in varied amounts by honey bee colonies. Honey yield produced after feeding diets was different. Results (table 6) depicted that cost for Diet-1 was Rs. 321.41, for Diet-2 was Rs. 255 and for Diet-3 it was Rs. 352, Diet-4 it cost Rs. 245 whereas for D-5 it was Rs. 264 per colony. Maximum profit was recorded for colonies receiving was noticed for bee colonies who were given Diet-1 @ Rs. 4200 followed by Diet-3, @ Rs. 2648, D-2 @ Rs. 2345, Diet-4 @ Rs. 1855 and lowest @ Rs. 836 for D-5 per colony.

4. Discussion

Results of diets consumption rates in our research work revealed that soybean fortified meal was highly consumed (74.34 g) by honey bees in seven days trailed by date enriched food with the mean intake value of 64.23 g/7-days. The values of formulated foods consumption for sugarcane syrup and black gram fortified diets were 57.43 g and 48.12 g/bee colony, correspondingly. Lowest consumption was noted for grinded groundnut (64.62 g) which was statistically less than the entire fed diets in the current

Table 4
Measurements of queen cells and body weight of neonate queens regarding different diets.

Artificial diets (30% solution of each)						Control	F-test
Characteristics	Soybean Flour	Sugar cane syrup	Date Paste	Black gram flour	Grinded groundnuts		
Queen cell width (mm)	6.95 ± 2.01a	6.03 ± 0.71b	6.67 ± 0.78ab	5.43 ± 0.39c	4.87 ± 0.41 cd	4.10 ± 0.23d	ns
Queen cell length (mm)	0.2041 ± 0.023a	0.18 ± 0.03b	0.19 ± 0.06a	0.16 ± 0.04 cd	0.14 ± 0.010d	0.8 ± 0.01a	*
Newly emerged queen weight (g)	12.41 ± 0.81a	10.23 ± 0.67b	11.94 ± 0.54a	9.87 ± 0.71b	7.26 ± 0.80c	5.31 ± 0.75d	**
Queen cell opening diameter (mm)	28.10 ± 2.89a	24.34 ± 2.11ab	27.82 ± 3.23a	21.45 ± 1.30b	17.39 ± 2.57c	12.64 ± 2.05d	ns

Data are displayed as average ± standard deviation (S.D.) and assembled rendering to Duncan's multiple range test (α = 0.05). Values having different lettering are statistically different. Significance based on F-test: ns = p > 0.05; p < 0.05*, p < 0.01;**

Table 5
Coefficients of correlation between the queen cells and body weight of newly emerged queens.

Traits	Queen cell opening diameter	Queen cell length (mm)	Newly emerged queen weight	Queen cell width
Queen cell width (mm)	±0.001	±0.052	±0.070	–
Queen cell length (mm)	± 0.342**	–	±0.021	±0.231
Newly emerged queen weight (g)	±0.028a	±0.171	–	±0.250
Queen cell opening diameter (mm)	–	±0.104ab	± 0.001	±-0.30

Results are revealed as average ± standard error (S.E.). Strength of correlation was projected as under: >0.6 = strong; 0.3–0.6 = moderate; <0.3 = weak

Table 6
Economics of using pollen substitute diets in beekeeping.

Diets	Gross investment per colony (Rs.)	Gross return per colony (Rs.)	Profit (Rs.)
Diet 1	321.41	4200	3878.59
Diet 2	255	2600	2345
Diet 3	352	3000	2648
Diet 4	245	2100	1855
Diet 5	264	1100	836

research work. Noteworthy variations were observed in the mean diet consumption in entire examined honey bee colonies ($P < 0.05$). Similar findings have been coded by different researchers previously where bees consumed artificial proteinaceous foods than the naturally available pollens (Saffari et al., 2004; Mattila and Otis, 2006). Such as, soybean enriched diet consumption flours of soybean, wheat, maize and gram as pollen replacements for *A. mellifera* brood have also been used. For example, Blends of soybean flour + honey + water showed the excellent pollen alternative among all the four blends and supported a healthy population of bees after nourishing these diets (Usha et al., 2014). Similarly many studies noted a significant worker sealed brood by feeding the bee's colonies with pollen alternate enriched foods for growing the worker brood area (Saffari et al., 2010; Sihag and Gupta, 2011; Islam et al., 2020). There are many reports which supported our results that after providing supplementary dietary substances resulted in more number of frames/colony over bee colonies in control which resulted in maximum honey production (Sabir et al., 2000; Dodologlu et al., 2004; De Grandi-Hoffman et al., 2008; Rashid et al., 2013; Sihag and Gupta, 2013). Results of honey yield results are in confirmation with the results of Rashid et al. (2013) who reported higher honey yield in colonies provided different pollen substitute diets. The proportion of foragers coming back the hive and impacts of prepared diets was found significant ($p < 0.05$). The results of our study are in line with Delaplane et al. (2013) who observed enhanced foraging activities in bees fed with soybean enriched diet. Many researchers have noticed that fortified diet provides greater energy to the forager bees to fly apart and bring pollens compared to bees fed less fortified diet. Avni et al. (2009) and Wright et al. (2018) noted enhanced foraging activity with enriched diet over as was recorded in my research work. Bee colonies can react to pollen tricking by growing their foraging activity (Keller et al., 2005). Hence, provision of natural pollen alternate diets can equip the bee colonies with augmented brood activities leading to substantial honey yield.

Maximum values of thorax weight (33.12 and 32.54 mg/bee) were noted in workers fed on soybean flour and date paste diets. Many researchers have examined the impacts of formulated diets on bee thorax weight (Sagili et al., 2005, Ahmed et al., 2019; Riessberger-Gallé et al., 2009). The thorax weight in all these research works was noted superior over corresponding control bee colonies. Results of number of wax cells built are different from those of Wilkinson and Brown (2002) but in line with Okuyan and Akyol (2018). The maximum mean weight of newly emerged queen in my research work was noticed in Soybean flour fed bees and was significantly higher compared to the other diets. Our results are in line with De Jong et al. (2009) noted down remarkable superiority of artificial bee bread over control as was observed in my research work. Result increased number of queen cells in this study are in line with in line with Islam et al. (2020). But contradictory with those documented by Gençer et al. (2000), who noticed that bees colonies fed with sugary solution blend with vitamin resulted in significant augmentation in queen cells. Results of wax cell build bees colonies fed on diverse artificial diets in our research were greater wax-built cells, whereas the number of the cells in control bees was remarkably less compared than the artificial diets. Results of enhanced dimensions of queen cells in our research work with soybean fortified diet were supported by Dolasevic et al. (2019) in bees fed with artificial diet. Highest honey yield i.e. 8.74 kg per colony was collected from soybean fortified diet fed bee colonies while the minimum (4.3 kg/colony) yield was extracted from the bee colonies in control colonies deprived of pollen alternate foods. Many researchers have examined the consumption rates of bees for different formulated diets. Our results were supported by Islam et al. (2020) whom noted a substantial honey yield by feeding the bee's colonies with pollen alternate enriched foods.

5. Conclusion

From it concluded that these artificially prepared fortified diets are beneficial as a momentary solution to evade dwindling of the bee colonies in harsh foraging circumstances. Apiarists should display carefulness when using them as a long-term remedy to the deficiency of pollen plenty and variety. We also revealed the significance of measuring numerous colony and separate bee parameters to assess the appropriateness of a diet. In our research work, we recommend soybean and date paste enriched diets for the successful and substantial honey bee colony development leading to augmented honey yield.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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