ANADOLU, J. of AARI
ISSN: 1300-0225 (Print)
E-ISSN: 2667-6087 (Online)
2022, 32 (2): 217-227
DOI: 10.18615/anadolu.1173055

Economic Analysis of Honey Bee Colonies Fed with Different Pollen Diets before Wintering

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Received (Geliş tarihi): 13.09.2022 Accepted (Kabul tarihi): 18.11.2022

ABSTRACT: *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. In this study, an economic analysis of supplementary feeding models formed by giving different protein diets and carbohydrates (sugar-water mixture) needed until early spring to colonies prepared with equal strength in the autumn period was performed. The feeding experiment was carried out in 6 groups with 8 colonies in each group and a total of 48 colonies. Experimental groups were as follows:* ***Papaver somniferum L.*** *pollen,* ***Cistus creticus L.*** *pollen, mixed pollen, bee cake, syrup, and control. In this study, after determining the production costs per hive for the experimental groups, it was determined whether the bee frame values per hive covered the production costs. It could be concluded that feeding with P. somniforum pollen is slightly more advantageous than other feeding groups when the results of the pre-winter, winter and early spring periods are evaluated together. The ratio of bee frame value per hive to cover the production cost was calculated as 40.65% before winter, 102.98% in winter and 98.66% in early spring for the feeding with P. somniferum pollen. In terms of relative profitability, the protein diet with the closest performance to P. somniferum pollen was C. creticus pollen, the relative profitability was found to be lower in other feeding groups.*

Keywords: *Honey bees, pollen, profitability, supplementary diets.*

Kışlatma Öncesi Farklı Polen Diyetleri ile Beslenen Bal Arısı Kolonilerinin Ekonomik Analizi

ÖZ: *Beslenme her canlı için bir zorunluluktur. Bal arıları normal koşullarda besin madde ihtiyaçlarını doğal floral kaynaklardan karşılamaktadır. Yetersiz floral kaynakların olduğu durumlarda ise koloniler için ek besleme yapılması gereklidir. Bu çalışmada sonbahar döneminde eşit güçte hazırlanan kolonilere farklı protein diyetlerinin ve erken bahara kadar ihtiyaç duyulan karbonhidratın (şeker-su karışımı) verilmesiyle oluşan ek besleme modellerinin ekonomik analizi yapılmıştır. Besleme denemesi her grupta 8 koloni olacak şekilde 6 grup ve toplam 48 koloni üzerinde yürütülmüştür. Deneme grupları haşhaş (****Papaver somniferum L.)*** *poleni, pamucak (****Cistus creticus L.)*** *poleni, karışık polen, arı keki, şurup ve kontrol olmak üzere altı farklı gruptan* *oluşmaktadır. Bu çalışmada deneme grupları için kovan başına üretim masrafları ortaya konulduktan sonra kovan başına arılı çerçeve değerlerinin üretim masraflarını karşılayıp karşılamadığına bakılmıştır. Kış öncesi, kış ve erken ilkbahar dönemlerinin sonuçları birlikte değerlendirildiğinde, haşhaş poleni ile yapılan beslemenin diğer besleme gruplarına göre biraz daha avantajlı olduğu ortaya çıkmıştır. Haşhaş poleni ile yapılan beslemede kovan başına arılı çerçeve değerinin üretim masrafını karşılama oranları kış öncesinde %40,65, kış döneminde %102,98 ve erken ilkbahar döneminde %98,66 olarak hesaplanmıştır. Nisbi karlılık açısından haşhaş polenine en yakın olan protein diyeti pamucak polenidir. Diğer besleme gruplarında ise nisbi karlılık haşhaş ve pamucak poleni ile yapılan deneme grubundan daha düşük bulunmuştur.*

Anahtar kelimeler: *Bal arıları, polen, karlılık, destekleyici besinler.*

INTRODUCTION

Beekeeping is an environmentally friendly production model and an important economic activity that also contributes to the rational management of natural resources (Thrasyvoulou, 1998). Sustainability in beekeeping depends on the honey bee's continuous access to food sources (Pilati and Fontana 2018). Mobile beekeeping is done in many countries to benefit from floral resources (Cejvanovic *et al*., 2011; Jeločnik *et al*., 2013; Koprivlenski *et al*., 2015; Cengiz and Dülger, 2018). Rapid and continuous climatic changes have become an important problem for beekeeping in recent years. It was found that the two most important factors affecting honey production are unsuitable climatic conditions and wintering loss (Aksoy *et al*., 2017). Pollen diet plays an important role in the life of honeybees. A balanced diet impacts the physiology, biochemistry, immunity, and histology of workers as well as the development of larvae (Bryś *et al*., 2021; Topal *et al*., 2022; Sarioğlu-Bozkurt *et al*., 2022).

For beekeeping's sustainability, it is necessary to cope with emerging nutritional problems. Quality and quantity of nutrients are important parameters for the survival of organisms. As a result of inadequate and unbalanced nutrition, organisms have increased stress, and decreased reproductive ability and resistance to diseases. Supplementary feeding is inevitable in unfavourable circumstances due to the shortage of natural nutrients caused by biotic and abiotic factors for honeybees to perform their life functions and increase colony performance. Although the first thing that comes to mind in the diet of honeybees is the "sugar" diet, the most important nutrient for honeybees is protein. The protein requirement of the honeybee is met by quality fresh pollen. In recent years, many commercial ready-made cakes offered to the sector have been sold to meet the protein needs of colonies. Since these cakes do not contain enough protein or contain additives, they cannot be an alternative to natural pollen (Topal *et al*., 2019; Paray *et al*., 2021).

There are many studies on the effects of feeding colonies with different nutrient groups on bees and the points to be considered during the application. Studies on economic analysis of pollination, honey production cost, package beekeeping, country or regional beekeeping have been carried out. However, economic analyses of feeding and supplementary feeding costs have been limited (Saner *et al*., 2004; Bianca *et al*., 2011; Leonhardt *et al*., 2013; Sihang and Gupta, 2013; Makri *et al*., 2015; Vaziritabar and Esmaeilzade, 2016; Bixby *et al*., 2017; Ceyhan and Canan, 2017; Blanc *et al*., 2018; Adanacıoğlu *et al*., 2019; Vercelli *et al*., 2020; Vrabcová and Hájek, 2020; Aleskerova and Todosiichuk, 2021; Zalilova *et al*., 2021).

Economic analysis of supplementary feeding models formed by giving different protein diets and carbohydrates (sugar-water mixture) needed until early spring to colonies prepared with equal strength in the autumn period was performed in this study. The present study generally consists of three main parts. Production costs per hive are given for 6 different feeding media in the first part, followed by the ratio of bee frame values per hive to cover production costs in the second part. In the conclusion of the study, the relative profitability results of alternative feeding options' for pre-winter, winter and early spring periods were evaluated together, and suggestions were made about the optimum feeding environment for beekeeping enterprises.

Supplementary feeding during periods of insufficient floral resources is considered very important for the sustainability of colonies, particularly in recent years, when climatic changes have been experienced frequently. In addition, it is necessary for the profitability of beekeeping businesses to choose an optimum feeding condition by comparing the cost of the preferred feeding condition for colonies with the frame values of the bee in the hive. In this context, the following hypothesis was developed in the present research.

H1. Supplementary feeding of bee colonies during periods of insufficient floral resources differs economically for each selected feeding condition.

The economic results of experiments conducted by Sihang and Gupta (2013) in India support this hypothesis. This study indicated the economic impact of four pollen replacement diets to aid the development of colonies during the hot summer period. According to the results, the diet consisting of soybean flour, yeast extract, honey, vitamins, and minerals was found to be more advantageous than the other options in terms of the number of frames per hive, honey yield per hive and gross profit.

MATERIAL and METHODS

Study Design

The study was carried out in the Aegean Agricultural Research Institute apiary (NL 38°33′54" EL 27°3′27") located in İzmir Province. Sister queens produced from Efe Bee (*Apis mellifera anatoliaca*) in 2020 were used in the experimental colonies. Colonies were formed on 14 September 2020 from 3 frames (1 honey-pollen, 1 brood comb, 1 empty comb) and 1 kg package of bees. Experimental groups were prepared as a total of 24 bee frames. Experimental groups consisted of 6 different groups with 8 colonies in each: *Papaver somniferum* L. pollen, *Cistus creticus* L. pollen, mixed pollen, bee cake, syrup, and control.

P. somniferum, an industrial plant found in the market, was used as a monofloral pollen source, *C. creticus* was used as a natural pollen source, mixed spring pollen and syrup made from beet sugar were also used in the study. Pollen sources were selected from those produced in the market and easily available. The fresh pollen from the producers was stored in the deep freezer until use. Particularly, ready-made commercial bee cakes with pollen additives were preferred. Fresh pollen was moistened slightly with sugar water, shaped to resemble meatballs and places in a plastic bag on the honeycombs. An equal amount of pre-wintering feeding (7 times) was made according to the needs of the colonies in all groups to ensure the freshness of the pollen and to observe the consumption and storage rate. The colony was fed with a 2:1 sugar-water mixture for the formation of honey stores (Somerville, 2000; Akyol *et al.*, 2006; Somerville, 2010).

The trial started on 14 September 2020 and ended on 14 March 2021. The amount of feeding provided to the colonies during the experiment is presented in Table 1.

Table 1. Consumptions of groups during the trial
Çizelge 1. Deneme boyunca grup tüketimleri

Years	Nutrient form	Control	Syrup	Bee cake	*P. somniferum* pollen	*C. creticus* pollen	Mixed pollen
2020	Sugar Syrup (lt)	1	10	10	10	10	10
	In cake form (gr)	-	-	1350	1350	1350	1350
2021	Sugar Syrup (lt)	-	4	4	4	4	4
	In cake form (gr)	-	-	-	-	-	-
Total	Sugar Syrup (lt)	1	14	14	14	14	14
	In cake form (gr)	-	-	1350	1350	1350	1350

Economic analysis

Production costs per hive were calculated within the scope of the economic analysis for 6 different feeding conditions: *P. somniferum* pollen, *C. creticus* pollen, mixed pollen, bee cake, syrup, and control. Production costs consist of variable and fixed costs. Variable costs include diet (*P. somniferum* pollen, *C. creticus* pollen, mixed pollen, bee cake, syrup, and control), basic honeycomb, medicine, and labour costs. An interest charge is added after taking the sum of the variable costs. Fixed costs consist of interest, depreciation, and management costs of used hives and tools-machines.

Opportunity cost represents the interest rate of production activity on both variable and fixed costs. Opportunity cost corresponds to the monetary return that a beekeeping company will obtain if it does not realize the investments in beekeeping activities but uses the financing it allocates for this investment in a bank against interest. The subsidized agricultural loan interest rate applied by public bank (T.C. Ziraat Bank) for beekeeping is the basis for calculating the interest charge for variable and fixed expenses within the scope of opportunity cost. The stated interest rate is 9% for both working capital and investment loans, with a 50% subsidized value of 4.5%. When calculating the interest rate of the expenses, the months covered by the pre-wintering period, the wintering period and the early spring periods are taken into account. Management costs are calculated as 3% of variable costs. The straight-line method was applied in the amortization calculations. While applying this method, the value of the fixed costs is divided by their average economic life.

After revealing the production costs per hive for 6 different feeding conditions, it was examined whether the bee frame values per hive cover the production costs. Bee frame values per hive were calculated under all feeding conditions and the bee frame values per hive were then divided by the production costs per hive. The ratio of covering the production cost of the bee frame value per hive above 100% is considered a critical point in the economic analysis. If this ratio is 100%, the value of the bee frame per hive is equal to the production cost, in other words, the monetary amount of the bee frame in the hives covers the production cost. Furthermore, absolute profit was calculated for each hive in this study. While calculating the absolute profit, the production costs per hive were subtracted from the bee frame values per hive. Thus, the profitability level of feeding per hive was determined in the pre-winter, winter and early spring periods.

RESULTS and DISCUSSION

RESULTS

An economic analysis was carried out comparing the costs of supplementary feeding with different pollen sources in the autumn period with the bee frame values in the pre-wintering, wintering, and early-spring periods in this study. Production costs per hive were calculated for 6 different feeding groups.

The production costs for the pre-winter period in table 2 are given in detail. When the production costs are analyzed according to the feeding conditions, the highest production cost per hive was seen in the feeding with *P. somniferum* pollen at US$55.65. This is followed by feeding conditions with *C. creticus* pollen costing US$55.48, and mixed pollen costing US$55.31. As seen in Table 2, production costs per hive are very close to each other for *P. somniferum*, *C. creticus* and mixed pollen feeding conditions for the pre-winter period.

Table 2. Production costs under different feeding conditions in the pre-winter period (US$/hive).
Çizelge 2. Kış öncesi dönemde farklı besleme koşullarında üretim masrafları (US$/kovan).

Cost items	P. *somniferum* pollen	C. *creticus* pollen	Mixed pollen	Bee cake	Syrup	Control
Supplementary feeding costs	12.07	12.07	12.07	6.38	4.96	0.50
Basic honeycomb	2.39	2.22	2.06	2.22	1.97	1.97
Medication	0.66	0.66	0.66	0.66	0.66	0.66
Labour	15.01	15.01	15.01	15.01	15.01	15.01
Bee colony	19.74	19.74	19.74	19.74	19.74	19.74
Sum of Variable Cost Items (US$/hive) (1)	49.87	49.70	49.54	44.01	42.34	37.88
Interest on variable costs (4.5%) (3 months) (2)	0.56	0.56	0.56	0.49	0.48	0.43
Total Variable Costs (1+2) (a)	50.43	50.26	50.10	44.50	42.82	38.31
Interest charge of the used hive (4.5%) (3 months)	0.30	0.30	0.30	0.30	0.30	0.30
Interest charge for the used tool-machine (4.5%)	0.47	0.47	0.47	0.47	0.47	0.47
Depreciation for hives	2.63	2.63	2.63	2.63	2.63	2.63
Depreciation for tool-machine	0.31	0.31	0.31	0.31	0.31	0.31
Share of management costs (3%)	1.51	1.51	1.50	1.34	1.28	1.15
Total Fixed Costs (US$/hive) (b)	5.22	5.22	5.21	5.05	4.99	4.86
Total Production Costs (US$/hive) (a+b)	55.65	55.48	55.31	49.55	47.81	43.17

Production costs per hive for other feeding conditions in the pre-winter period were US$49.55 for commercial bee cake, US$47.81 for syrup and US$43.17 for control conditions. If the control group is not taken into account, the lowest production cost per hive was obtained in the feeding with syrup. In the control feeding, the syrup was fed once at the beginning of the experiment, and there was no further feeding. Therefore, there is a certain amount of food costs, even if it is very small. Thus, the production cost is lower in the control conditions compared to other feeding conditions due to relatively lower feeding costs.

The production costs for the different feeding conditions in the winter period are shown in Table 3. The highest production cost was US$33.86 in the *P. somniferum* pollen feeding when the production costs were analyzed. This was followed by *C. creticus* and bee cake feeding having the same cost level of 33.68 US$. Production costs according to other feeding conditions, respectively; US$33.52 for mixed pollen, US$33.42 for syrup, and US$32.90 for the control group. No supplementary feeding was done in the control group during the winter period. It could be seen that the lowest production cost is in the feeding made with syrup with no significant difference compared to the other groups in the winter period.

Production costs for different feeding conditions in the early spring period are shown in Table 4. The production cost per hive is higher in the *P. somniferum* pollen feeding group in the early spring compared to other feeding conditions in the pre-winter and winter periods. The production cost was calculated as US$38.01 per hive for the *P. somniferum* pollen feeding group. After *P. somniferum* pollen, the highest production cost per hive occurred in the *C. creticus* and bee cake feeding groups with 37.83 US$. These are followed by mixed pollen with US$37.67 and syrup feeding groups with US$37.57. As in other periods, the production cost per hive was lower in the control group in the early spring period, and this cost was 36.03 US$ per hive. If the control group is not taken into account, it can be said that the lowest production cost per hive is obtained in the feeding made with syrup.

The ratio of bee frame value to production cost per hive under different feeding conditions in the pre-winter, winter, and early spring periods, are given in Tables 5, 6 and 7, respectively. The distribution of these rates for three periods is shown in Figure 1.

In the pre-winter period, which includes the months of September, October, and November, it is observed that the bee frame values per hive under all feeding conditions do not cover the production costs. Moreover, absolute profit per hive was negative under all feeding conditions. The main point here is that the production cost coverage ratio of the bee frame value per hive is above 100%. The rate of 100% means that the bee frame value per hive is equal to the production cost; in other words, the monetary amount of the bee frame in the hives covers the production cost. In the pre-winter period, the rate of covering the production cost of the bee frame value per hive under different feeding conditions was achieved in the feeding group made with bee cake, with the highest rate of 42.60%. This rate was determined as 40.65% in the *P. somniferum* pollen feeding group, where the highest production cost per hive was observed in all three periods followed by the syrup (39.13%) and control (37.02%) groups. Mixed pollen (36.18%) and *C. creticus* (36.81%) groups have the lowest bee frame value ratio per hive to cover the production cost in the pre-winter period.

Table 3. Production costs in different feeding conditions in winter (US$/hive).
Çizelge 3. Kış döneminde farklı besleme koşullarında üretim masrafları (US$/kovan).

Cost items	*P. somniferum* pollen	*C. creticus* pollen	Mixed pollen	Bee cake	Syrup	Control
Supplementary feeding costs	0.50	0.50	0.50	0.50	0.50	0.00
Basic honeycomb	2.39	2.22	2.06	2.22	1.97	1.97
Medication	0.66	0.66	0.66	0.66	0.66	0.66
Labour	6.00	6.00	6.00	6.00	6.00	6.00
Bee colony	19.74	19.74	19.74	19.74	19.74	19.74
Sum of Variable Cost Items (US$/hive) (1)	29.29	29.12	28.96	29.12	28.87	28.37
Interest on variable costs (4.5%) (2 months) (2)	0.22	0.22	0.22	0.22	0.22	0.21
Total Variable Costs (1+2) (a)	29.51	29.34	29.18	29.34	29.09	28.58
Interest charge of the used hive (4.5%) (2 months)	0.20	0.20	0.20	0.20	0.20	0.20
Interest charge for the used tool-machine (4.5%)	0.32	0.32	0.32	0.32	0.32	0.32
Depreciation for hives	2.63	2.63	2.63	2.63	2.63	2.63
Depreciation for tool-machine	0.31	0.31	0.31	0.31	0.31	0.31
Share of management costs (3%)	0.89	0.88	0.88	0.88	0.87	0.86
Total Fixed Costs (US$/hive) (b)	4.35	4.34	4.34	4.34	4.33	4.32
Total Production Costs (US$/hive) (a+b)	33.86	33.68	33.52	33.68	33.42	32.90

Table 4. Production costs in different feeding conditions in early spring (US$/hive).
Çizelge 4. Erken ilkbahar döneminde farklı besleme koşullarında üretim masrafları (US$/kovan).

Cost items	*P. somniferum* pollen	*C. creticus pollen*	Mixed pollen	Bee cake	Syrup	Control
Supplementary feeding costs	1.49	1.49	1.49	1.49	1.49	0.00
Basic honeycomb	2.39	2.22	2.06	2.22	1.97	1.97
Medication	0.66	0.66	0.66	0.66	0.66	0.66
Labour	9.01	9.01	9.01	9.01	9.01	9.01
Bee colony	19.74	19.74	19.74	19.74	19.74	19.74
Sum of Variable Cost Items (US$/hive) (1)	33.29	33.12	32.96	33.12	32.87	31.38
Interest on variable costs (4.5%) (2 months) (2)	0.25	0.25	0.25	0.25	0.25	0.24
Total Variable Costs (1+2) (a)	33.54	33.37	33.21	33.37	33.12	31.62
Interest charge of the used hive (4.5%) (2 months)	0.20	0.20	0.20	0.20	0.20	0.20
Interest charge for the used tool-machine (4.5%)	0.32	0.32	0.32	0.32	0.32	0.32
Depreciation for hives	2.63	2.63	2.63	2.63	2.63	2.63
Depreciation for tool-machine	0.31	0.31	0.31	0.31	0.31	0.31
Share of management costs (3%)	1.01	1.00	1.00	1.00	0.99	0.95
Total Fixed Costs (US$/hive) (b)	4.47	4.46	4.46	4.46	4.45	4.41
Total Production Costs (US$/hive) (a+b)	38.01	37.83	37.67	37.83	37.57	36.03

Table 5. Ratios of covering production cost of bee frame value per hive in different feeding conditions in the pre-winter period.
Çizelge 5. Kış öncesi dönemde farklı besleme koşullarında kovan başına arılı çerçeve değerinin üretim masrafını karşılama oranları.

Items	*P. somniferum* pollen	*C. creticus* pollen	Mixed pollen	Bee cake	Syrup	Control
Total production costs per hive	55.65	55.48	55.31	49.55	47.81	43.17
Average number of bee frames per hive	3.44	3.10	3.04	3.21	2.84	2.43
Bee frame value per hive (US$)	22.62	20.42	20.01	21.11	18.71	15.98
Production cost coverage ratio of bee frame value per hive (%)	40.65	36.81	36.18	42.60	39.13	37.02
Absolute profit (US$)	-33.03	-35.06	-35.30	-28.44	-29.10	-27.19

In the winter period, which includes December 2020 and January 2021, it was determined that the frame values per hive did not cover the production costs in feeding conditions other than *P. somniferum* pollen. Furthermore, absolute profit per hive was positive only in the *P. somniferum* pollen group. The production cost coverage ratio of the bee frame value per hive is above 100% in the *P. somniferum* pollen group, whereas it is below 100% in other feeding environments. In the winter period, the highest ratio of bee frame value per hive to cover the production cost under different feeding conditions was achieved with the *P. somniferum* pollen feeding condition with a rate of 102.98%. This rate means that for the *P. somniferum* pollen feeding condition, the amount of bee frame per hive can meet the production cost above the breakeven point in the winter period. The most important reason is that the number of bee frames obtained per hive with *P. somniferum* pollen feeding is higher than other feeding conditions. The second highest ratio of bee frame value per hive to cover the production cost was the *C. creticus* pollen feeding group (85.96%). For the rest of the groups, these rates are 73.49% for syrup, 71.44% for commercial bee cake, 69.54% for the mixed pollen group and 47.99% for the control group.

It was determined that the bee frame values per hive did not cover the production costs under all feeding conditions in the early spring period, including the months February and March. Besides, absolute profit per hive was negative under all feeding conditions. It was also determined that the production cost coverage ratio of the bee frame value per hive was below 100% in all feeding conditions. However, it is seen that these rates are quite close to 100% in *P. somniferum* and *C. creticus* pollen groups. In other words, this situation is very close to the breakeven point where income equals expense in these groups. In the early spring period, the highest rate of covering the bee frame value production cost of the per hive under different feeding conditions was obtained in *C. creticus* pollen groups with 99.37%. This is followed by the feeding medium made with *P. somniferum* pollen with a rate of 98.66%. On the other hand, it has been previously stated that the *P. somniferum* pollen feeding condition in the winter period is quite advantageous compared to the *C. creticus* pollen feeding condition in terms of the ratio of the bee frame value per hive to cover the production cost. However, in the early spring period, it is seen that the two different feeding conditions are very close to each other. When the results of the pre-winter, winter and early spring periods are evaluated together, it can be said that feeding with *P. somniferum* pollen is slightly more advantageous than feeding with *C. creticus* pollen. The rate of covering the bee frame value production cost of the per hive in feeding with *P. somniferum* pollen is 40.65% before winter, 102.98% in winter and 98.66% in early spring. On the other hand, in feeding with *C. creticus* pollen, these rates are respectively; 36.81%, 85.96% and 99.37% as seen in Figure 1. The production cost coverage ratio of the bee frame value per hive in the other feeding groups was 83.83% in the mixed pollen group, 79.50% in commercial bee cake, 77.05% in the syrup and 47.48% in the control group. In all three periods, there is no significant difference between these two feeding conditions in terms of production costs per hive. However, there is a difference in terms of the average number of bee frames per hive. The average number of bee frames per hive in the pre-winter, winter, and early spring periods in the *P. somniferum* pollen group; 3.44, 3.31, and 3.56, while these values were 3.10, 2.75, and 3.57 for *C. creticus* pollen group.

Table 6. The ratios of covering production cost of bee frame value per hive in different feeding conditions in winter period
Çizelge 6. Kış döneminde farklı besleme koşullarında kovan başına arılı çerçeve değerinin üretim masrafını karşılama oranları.

Items	*P. somniferum* pollen	*C. criticus* pollen	Mixed pollen	Bee cake	Syrup	Control
Total production costs per hive	33.86	33.68	33.52	33.68	33.42	32.90
Average number of bee frames per hive	3.31	2.75	2.21	2.29	2.33	1.50
Bee frame value per hive (US$)	34.87	28.95	23.31	24.06	24.56	15.79
Production cost coverage ratio of bee frame value per hive (%)	102.98	85.96	69.54	71.44	73.49	47.99
Absolute profit (US$)	1.01	-4.73	-10.21	-9.62	-8.86	-17.11

Table 7. The ratios of covering production cost of bee frame value per hive in different feeding conditions in the early spring period.
Çizelge 7. Erken ilkbahar döneminde farklı besleme koşullarında kovan başına arılı çerçeve değerinin üretim masrafını karşılama oranları.

Items	*P. somniferum* Pollen	*C. creticus* pollen	Mixed pollen	Bee cake	Syrup	Control
Total production cost per hive	38.01	37.83	37.67	37.83	37.57	36.03
Average number of bee frames per hive	3.56	3.57	3.00	2.86	2.75	1.63
Bee frame value per hive (US$)	37.50	37.59	31.58	30.08	28.95	17.11
Production cost coverage ratio of bee frame value per hive (%)	98.66	99.37	83.83	79.50	77.05	47.48
Absolute profit (US$)	-0.51	-0.24	-6.09	-7.76	-8.62	-18.92

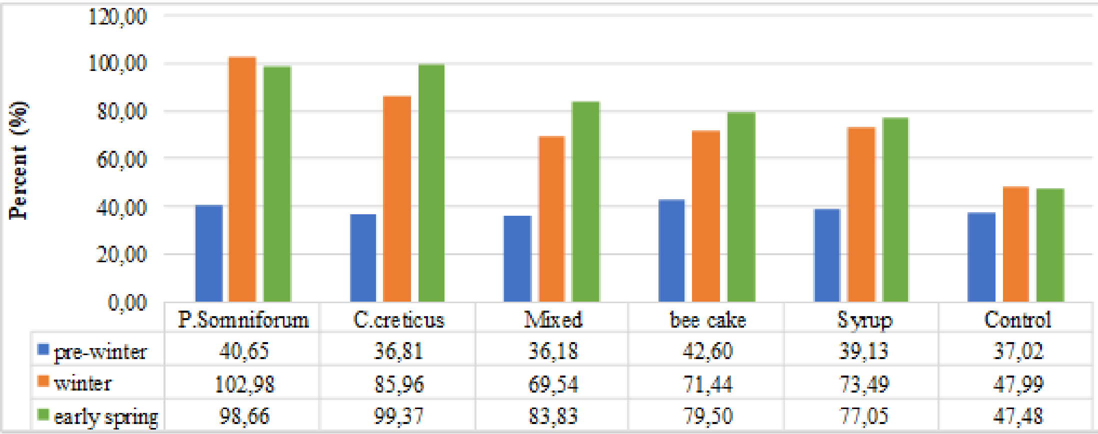

Figure 1. Ratios of covering production cost of bee frame value per hive in different feeding conditions in pre-winter, winter, and early spring periods.
Şekil 1. Kış öncesi, kış ve erken ilkbahar dönemlerinde farklı besleme koşullarında kovan başına arılı çerçeve değerinin üretim masrafını karşılama oranları.

DISCUSSION

In the literature, no study was found on the cost of supplementary feeding in beekeeping in Turkey. Therefore, this study will fill a gap in the field. Pollen is the most produced bee product after honey. Monofloral and polyfloral pollen sales prices are the same, and it is very important to choose pollen with rich nutritional content for honeybee development and bee health.

In the winter period, the *P. somniferum* pollen group had the highest ratio of bee frame value per hive to cover the production cost under different feeding conditions. This rate means that the amount of bee frames per hive can meet the production cost above the breakeven point in the feeding group made with *P. somniferum* pollen in the winter period. The most important reason is that feeding with *P. somniferum* pollen led to a higher number of bee frames obtained per hive compared to the other feeding conditions. The *C. creticus* pollen feeding group had the second highest ratio of bee frame value per hive to cover the production cost.

In the early spring period, the highest ratio of bee frame value per hive to cover the production cost was obtained in the *C. creticus* pollen group under different feeding conditions, followed by *P. somniferum* pollen group with a slight difference. It has been previously stated that the *P. somniferum* pollen group is quite advantageous compared to the *C. creticus* pollen group in the winter period in terms of the ratio of the bee frame value per hive to cover the production cost. In the early spring period, it is seen that the two different feeding groups are very close to each other. It can be stated that feeding with *P. somniferum* pollen is slightly more advantageous than *C. creticus* pollen when the results of the pre-winter, winter and early spring periods are evaluated together.

The findings of this study reveal that *P. somniferum* pollen is the most economically efficient feeding alternative in case of supplementary feeding to bee colonies during periods of insufficient floral resources. This result also supports our hypothesis that every selected nutrient is not economical in case of supplementary feeding to bee colonies during periods of insufficient floral resources. In the present study, *P. somniferum* pollen was more advantageous than other dietary options (*C. creticus* pollen, mixed pollen, bee cake, syrup, and control). Previous research results in this context also confirm this (Sihang and Gupta, 2013; Kumar and Agrawal, 2014; Islam *et al*., 2020; Kumar *et al*., 2021; Ullah *et al*., 2021). In consequence, the economic feasibility of some diets is more prominent among different dietary options in previous studies. The results of these studies are summarized below.

Sihang and Gupta (2013) studied the effects of four pollen replacement diets on the growth of bee colonies in India to support the development of colonies during the hot summer period. As a result, the diet consisting of soybean flour, yeast extract, honey, vitamins, and minerals was determined as the best option among the four artificial pollen replacement diets in terms of the number of frames per hive, honey yield per hive, and gross profit. In another study conducted in India, Kumar and Agrawal (2014) found that a diet consisting of defatted soy flour, brewer's yeast, soy protein hydrolysate, sugar, and glucose was more effective in bee colony feeding. Islam *et al.* (2020) in Pakistan, showed a diet consisting of soybean flour, Brewer's yeast, honey, powdered sugar, powder of Fenugreek and Turmeric, orange juice, A, D and E vitamins, and 150 ml sugar syrup provided the highest gross profit among four different feeding conditions. In the experiment using six different feeding conditions, Kumar *et al.* (2021) showed that the diet with a mixture of Brewer's yeast, gram, skimmed milk powder, sugar, and pollen is more advantageous than the other diets in terms of the number of frames in the hives and the amount of honey obtained. In another study, Ullah *et al.* (2021) obtained the highest maximum profit in the diet option composed of soybean flour, skimmed milk, sugar, honey, and glucose among five different feeding groups. In this study, it was emphasized that it is important to include soybeans in supplementary diets. In this context, it has been stated that pollen diets enriched with soybean can increase honey yield and profitability by accelerating the physiology of the honeybee.

CONCLUSION

In the present study, conducted in Izmir province of Turkey, an answer was sought to the question of which nutrient medium is ideal in terms of economic applicability in case of supplementary feeding to bee colonies during periods of insufficient floral resources. The results show that *P. somniferum* pollen is the most economically efficient feeding option in case of supplementary feeding to bee colonies. On the other hand, in different studies conducted in India and Pakistan, pollen diets enriched with soybeans come to the fore. It should be noted that these results may vary according to region and alternative diet options. In addition, convenient pollen diet options for the region and production conditions should not be ignored by beekeepers to provide economic sustainability for bee colonies during periods of insufficient floral resources.

Urbanization, intensive mechanization of agricultural lands, the intensification of monoculture agriculture, and the climatic changes in recent years indicate that the biggest problem in the future will be nutrition. Moreover, commercial bee cakes, which are sold with various additives in the market, cannot fully meet the needs of the honeybee. Quality food sources ensure the health of the honeybee and increase its lifespan. Therefore, in order to cope with the nutritional problem, which will be the biggest problem of the future, it is considered to be important for beekeepers to collect pollen during the periods when flower sources are available and to keep them in coolers to meet the future nutritional needs of their bees.

ACKNOWLEDGEMENT

This article was produced from the project “The Pollen Preferences of Honeybees and the Effects of Pollen Use in Winter on Colony Dynamic” (TAGEM/HAYSÜD/B/20/A4/P5/1890) supported by The Turkish Ministry of Agriculture and Forestry, General Directorate of Agricultural Research and Policies (TAGEM), We would like to acknowledge TAGEM and Aegean Agricultural Research Institute for their support.

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