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RESEARCH ARTICLE

Impacts of new artificial diets on activity and strength development of *Apis mellifera* honey bee colonies

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Abstract: One of the chronic problems that pose a serious threat for honey bees' continuity and survival is pollen and nectar deficiency caused by annual weather fluctuations. The current study aims to find an effective solution for this problem by providing honey bee colonies with diets characterized by appropriate cost, nutritional rich value, palatability and positive impacts on various biological activities. Three new artificial diets were prepared, diet W: based on wheat germ, diet S: based on soya beans and diet M: based on a mixture of equal proportions of wheat germ and soya beans. In the current study, several investigations have been performed including consumption rates of examined diets, sealed worker brood, stored honey areas, colonies' strengths and pollen grains' weights. Outstanding palatability rates were reported for examined diets, especially for diet S. Moreover, distinguished impacts for all investigated diets have been recorded by fed colonies, including sealed brood areas, produced honey areas, population densities and collected pollen. Consequently, the current study highly recommend diets W, S and M to be applied in apiaries due to their prominent results related to activity and strength development of honey bee colonies.

Key words: *Apis mellifera*, artificial feeding, wheat germ, soya beans

INTRODUCTION

Nectar and pollen availability are relevant to certain climatic circumstances, thus, throughout inappropriate dearth intervals, bees suffer food shortage, and accordingly, colonies should be supplied by artificial feeding (House, 1961; Feng, 2002 and Saffari et al., 2004).
Artificial feeding may have a crucial role in enhancing the efficacy of honey bee colonies by developing their biological activities, improving their production rates and strengthening their immunity (Skubida et al., 2008 and Zahra and Talal, 2008).

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The efficacy of several diets at several levels related to honey bees' colonies has been studied by many researchers (Standifer et al., 1960; DeGrandi-Hoffman et al., 2008; Sihag and Gupta, 2011; Gamal El-Dien, 2018 and Papežíková et al., 2019).
Substitute diets without pollen or supplement diets accompanied by pollen are the main forms of formulated diets utilized at dearth periods (Saffari et al., 2006).
From an economic point of view, the appropriate cost of prepared diet formulations can be considered a critical parameter in the evaluation process of formulated diets when compared with commercial expensive ready-made diets that have not been observed to be sufficiently effective in promoting colonies' growth and development.

This study aims to provide new artificial diet formulations characterized by diverse nutritional value and suitable cost, moreover, another aim is to evaluate diets' palatability and their predicted impacts on different biological parameters including brood rates, honey production, population density and collected pollen.

Materials and methods

Four groups of hybrid carniolan bee race with roughly equally strength colonies headed by queens of nearly the same age were established, one for each examined diet including three replicates, confronted with three replicates of control group that were fed only on sugar syrup (1 sugar: 1 water) throughout the time from 19 April 2018 to 22 September 2018 at the apiary of Faculty of Agriculture, South Valley university, Qena, Egypt. Wooden pollen traps were implemented during study time as shown in figure 1.
New Diet formulations were prepared by definite ratios as shown in table 1 based on two main proteinaceous sources: wheat germ belonging to cereals and soya beans belonging to legumes.

Table 1: Composition of examined diets' formulations (%):

Component	Diet W	Diet S	Diet M
Wheat Germ	30%	-	15%
Soya Beans	-	30%	15%
Brewer's yeast	10%		
Fenugreek	5%		
Pollen	5%		
Sugar	50%		

Estimation of diet's consumption rate was performed every 12 days interval by subtracting the unconsumed weight from the fresh diet's weight and dividing the result by the fresh weight.

Sealed worker brood and stored honey areas were estimated according to Jeffree, 1958, using grid square system and counting squares opposite to sealed brood.
Colonies' population densities were determined by estimating number of covered combs with bees according to DeGrandi-Hoffman et al., 2008.
Using pollen traps, pollen grains were collected and weighed daily and the total means of pollen weights were compared.

ANOVA analyses were implemented on given data; moreover LSD test was performed for means comparisons.

Results

1- Diets' consumption rates:

As clarified in table 2 that shows consumption rates of examined diets W, S and M. It was found that the highest value of total mean of consumption rates was recorded for diet S by 98.39% with significant variations in comparison with diets M and W by total means 94.19% and 92.97% respectively.

2- Sealed worker brood areas:

As elucidated in table 3, honey bee colonies fed on examined diets have recorded improved sealed worker brood rates, the highest values were reported for colonies fed on diets W and S by total means of 207.26 and 205.18 $inch^2$ respectively, followed by colonies fed on diet M by198.02 $inch^2$.
Moreover, significant variations in brood production rates were recorded between colonies fed on examined diets and control colonies that have recorded total mean of 124.3 $inch^2$.

3- Stored honey areas:

Distinguishable rates of stored honey areas were observed through table 4 for treated colonies in comparison with control colonies.

The highest rate of stored honey areas was recorded for colonies fed on diet S by total mean of 637.29 inch^2 with significant variations with colonies fed on diet W by total mean of 479.21 inch^2 and control colonies by total mean of 280.49 inch^2, and with no significant variation with colonies fed on diet M by total mean of 567.54 inch^2.

4- Colonies' strengths:

As shown in table 5, growing rates have been observed of colonies population densities by total means of 5.9, 5.57 and 5.39 covered combs for colonies fed on diets S, M and W respectively, with significant variations in comparison with control colonies that have recorded total mean of 4.55 covered combs.

5- Collected Pollen weights:

Throughout the entire study time, and as shown in table 6, collected pollen weights were reported by total means of 28.72, 26.56 and 19.28 gm for colonies fed on diets M, W and S respectively, while, control colonies have recorded the lowest total mean by 6.22 gm.

Discussion

Given consumption rates' findings agreed with previous studies that have pointed to soya beans diets and recommended it as a high palatable proteinaceous component (Sihag and Gupta, 2011 and Mahfouz, 2016).
However, diet's palatability is not necessarily the main parameter that can assess its value. Nutritional components included in the diet are the main value of any diet due to its biochemical need that plays a substantial role in maintaining and enhancing colonies activities (De Groot, 1953 and De Grandi Hoffman et al., 2008).
Interestingly, given brood rates findings reinforce what Chhuneja et al., 1993 and Abd El-Wahab et al., 2016 have showed regarding the role of artificial feeding in brood and colony development. Shoreit and Hussein, 1993 have reported higher produced honey rates upon feeding some colonies on proteinaceous diets in comparison with other colonies fed on sugar diets only, moreover, Peixin and BaoHua, 2010 have observed the effect of pollen depression on honey production levels. In this context, given results of stored honey areas did not differ from previous observations where promising significant rates have been reported between fed colonies on examined diets, especially S diet when compared with control colonies.
Furthermore, the notable high values of colonies population densities fed on examined diets agreed with Kumar and Agrawal, 2013 who have confirmed the direct relationship between the development of colonies' densities and supporting them with supplemental diets.
Moreover, given findings of collected pollen weights via colonies fed on examined diets might be consistent with Ibrahim, 1973 and Mahfouz, 2016 who have reported improved rates of gathered pollen upon feeding honey bee colonies with artificial diets.
Finally, food diversity of applied diets, especially for diet M and enrichment of these diets with nutritional carbohydrates, proteins, fats, minerals and vitamins might interprets reported findings, in particular, extremely high values of some measurements. Therefore, nutritional analyses of substitutes and physiological investigations of fed bees should be implemented in order to maintain deeper understanding of artificial feeding impacts on the activity and strength development of honey bee colonies.

Conclusion

Based on their reported outstanding impacts at different levels including palatability rates, brood areas, stored honey, colony strength and gathered pollen, in addition to their appropriate costs, the authors highly recommend diets W, S and M to be applied in apiaries; moreover, more studies and investigations on these diets are needed to be commercially successful.

Figure 1: Used pollen trap with dimensions 37 cm length * 10.5 cm width * 12.5 cm height

Table 2: Consumption rates (%) of provided diets to honey bee colonies:

Date	Diet W	Diet S	Diet M	L.S.D. 5%
2/5/2018	88.67	99	89.33	2.79
15/5/2018	89	94	97	
28/5/2018	88.67	98.67	99.33	
10/6/2018	88.33	98	98.33	
23/6/2018	91.33	99	92.33	
6/7/2018	98	99.33	92	
19/7/2018	98.67	99	90	
1/8/2018	97	98	96.67	
14/8/2018	94.33	98.67	97	
27/8/2018	95.67	99	98	
9/9/2018	96	99	92.33	
22/9/2018	90	99	88	
Means	92.97^{b} (± 1.16)	98.39^{a} (± 0.42)	94.19^{b} (± 1.14)	

Means followed by different letters are significantly different ± SE

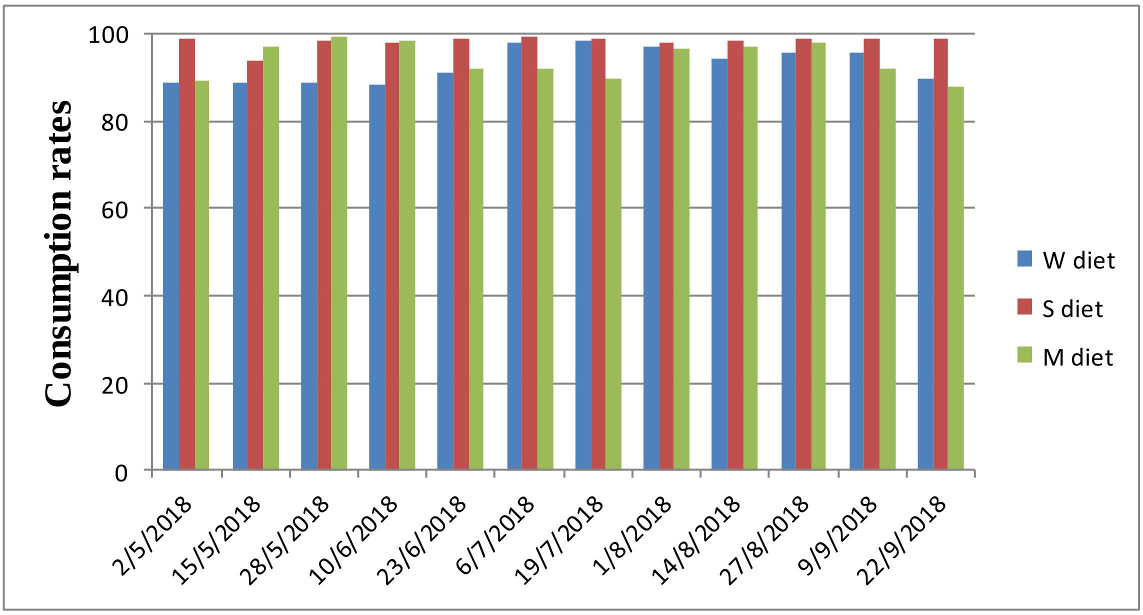

Figure 2: Consumption rates (%) of provided diets to honey bee colony.

Table 3**:** Sealed worker brood areas (inch^2) of honey bee colonies fed on examined diets confronted with unfed control colonies:

Date	Control	W diet	S diet	M diet	L.S.D. 5%
19/4/2018	110.05	129.17	118.83	117.54	39.06
2/5/2018	91.45	126.58	131.75	118.84	
15/5/2018	88.35	114.96	129.17	118.83	
28/5/2018	89.9	189.88	188.58	182.13	
10/6/2018	147.25	250.58	217	188.58	
23/6/2018	174.38	226.04	220.88	204.09	
6/7/2018	155	267.38	222.17	248	
19/7/2018	162.75	250.58	260.92	254.46	
1/8/2018	147.25	229.92	240.25	237.67	
14/8/2018	131.75	211.83	209.25	222.17	
27/8/2018	116.25	273.83	255.75	253.17	
9/9/2018	124	258.33	268.67	268.67	
22/9/2018	77.5	165.33	204.08	160.17	
Means	124.3^b (± 8. 79)	207.26^a (± 15.71)	205.18^a (± 13.99)	198.02^a (± 15.34)	

Means followed by different letters are significantly different ± SE

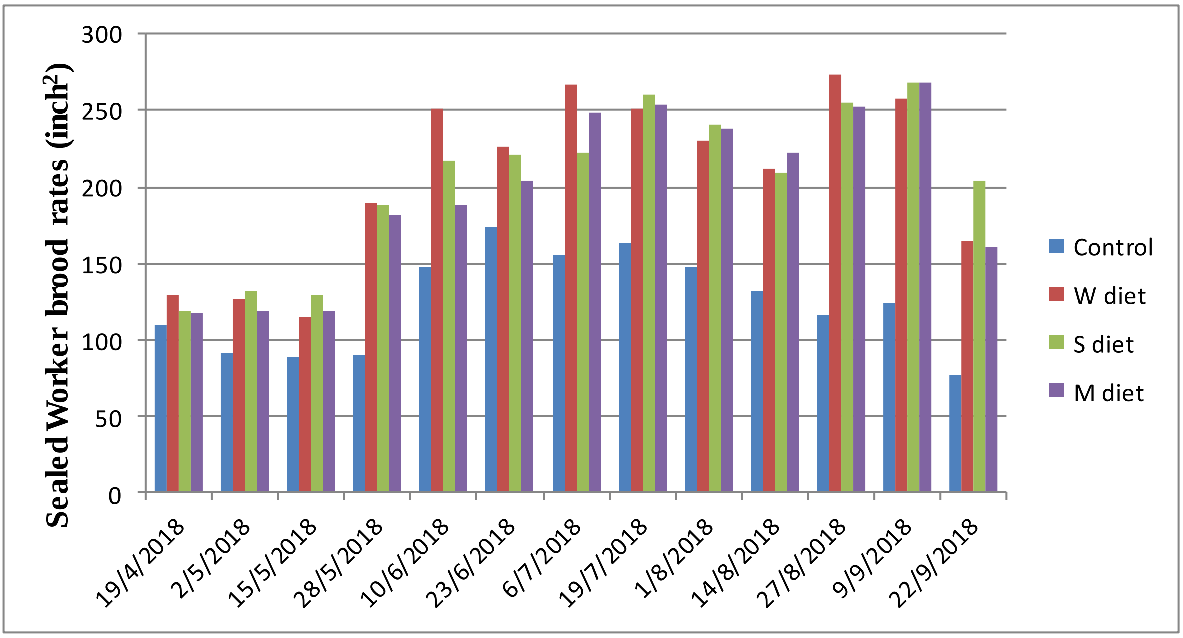

Figure 3: Sealed worker brood areas (inch^2) of honey bee colonies fed on examined diets confronted with unfed control colonies.

Table 4: Stored honey areas (inch^2) of honey bee colonies fed on examined diets confronted with unfed control colonies:

Date	Control	W diet	S diet	M diet	L.S.D.
19/4/2018	201.5	191.17	217	222.17	103.32
2/5/2018	217	284.17	599.33	322.92	
15/5/2018	286.75	475.33	639.38	477.92	
28/5/2018	294.5	527	723.33	596.75	
10/6/2018	457.25	498.58	692.33	532.17	
23/6/2018	418.5	558	793.08	697.5	
6/7/2018	255.75	483.09	703.96	612.25	
19/7/2018	162.75	507.63	604.5	601.92	
1/8/2018	189.88	493.42	498.58	578.67	
14/8/2018	197.63	503.75	573.5	596.75	
27/8/2018	263.5	550.25	671.67	658.75	
9/9/2018	333.25	545.08	787.92	738.83	
22/9/2018	368.13	612.25	780.17	741.42	
Means	280.49^c (± 25.46)	479.21^b (± 31.89)	637.29^a (± 42.81)	567.54^{ab} (± 42.23)	

Means followed by different letters are significantly different ± *SE*

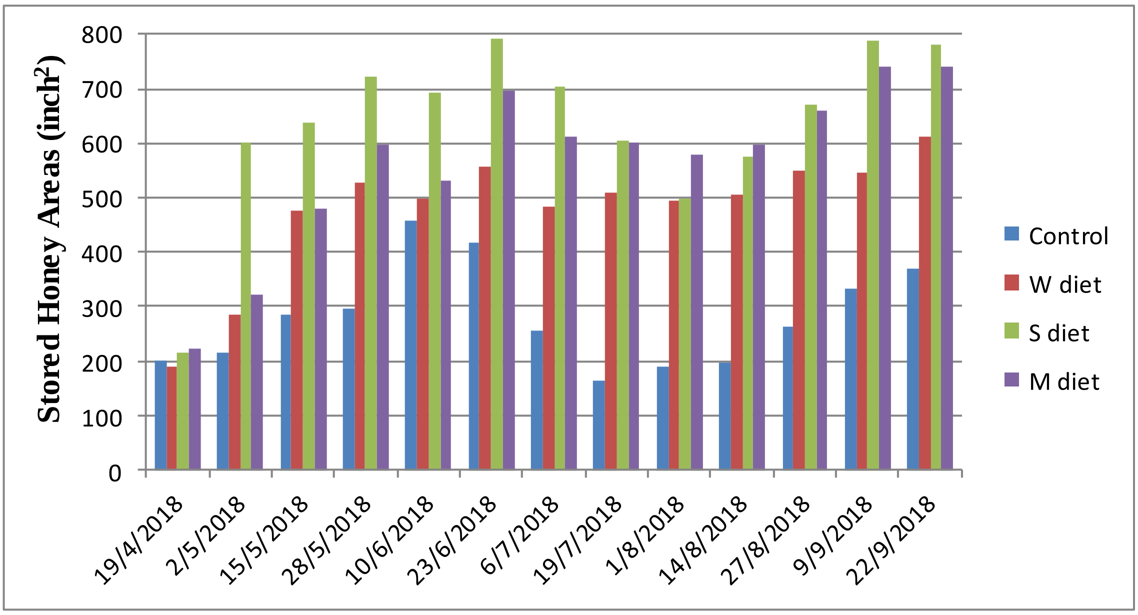

Figure 4: Stored honey areas (inch^2) of honey bee colonies fed on examined diets confronted with unfed control colonies

Table 5: Colonies' strengths (no. of covered combs) of honey bee colonies fed on examined diets confronted with unfed control colonies:

Date	Control	W diet	S diet	M diet	L.S.D. 5%
19/4/2018	4	4	4	4	
2/5/2018	3.88	3.54	3.92	4.38	
15/5/2018	3.5	3.79	4	4.5	
28/5/2018	4	5.42	4.71	4.79	
10/6/2018	4	6.21	5.96	6.5	
23/6/2018	4.88	5.75	5.88	5.88	
6/7/2018	4.88	6.42	6.92	5.92	0.77
19/7/2018	5.38	5.88	6.46	5.75	
1/8/2018	4.5	5.33	6.92	5.79	
14/8/2018	4.5	5.38	7.25	6	
27/8/2018	5	6.59	6.63	6.09	
9/9/2018	5.25	6	7.09	6.46	
22/9/2018	5.38	5.79	6.96	6.38	
Means	4.55^{b} (± 0.17)	5.39^{a} (± 0.28)	5.9^{a} (± 0.36)	5.57^{a} (±0.24)	

Means followed by different letters are significantly different ± SE

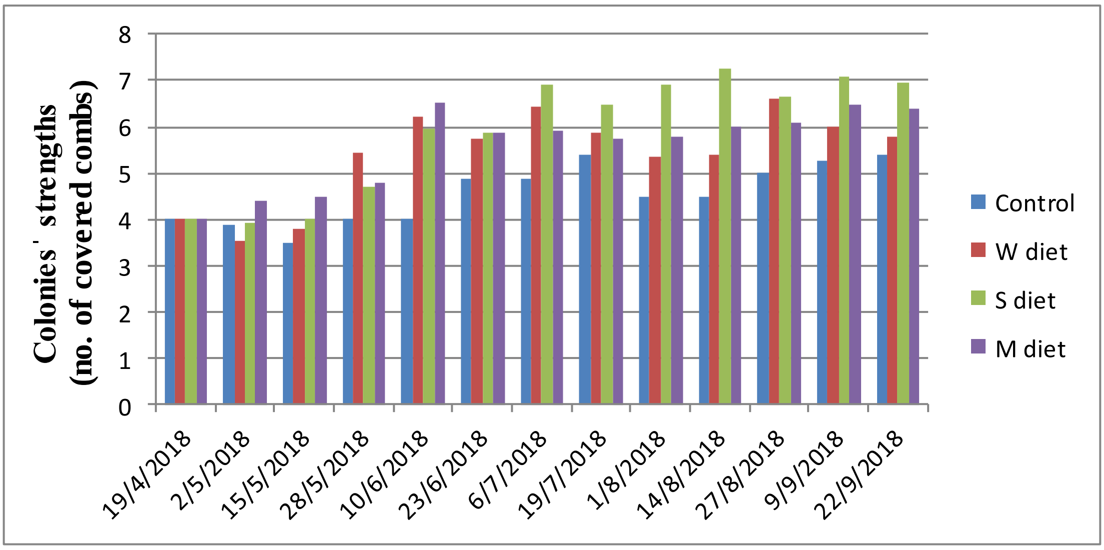

Figure 5: Colonies' strengths (no. of covered combs) of honey bee colonies fed on examined diets confronted with unfed control colonies.

Table 6: Pollen weights (gm) collected by honey bee colonies fed on examined diets confronted with unfed control colonies:

Date	Control	W diet	S diet	M diet	L.S.D. 5%
April-2018	3.33	21	10.33	10	24.68
May-2018	11.33	32.67	16.67	14	
June-2018	5	27	17	11	
July-2018	12.67	36	23.67	18	
August-2018	3	32	35	107.33	
September-2018	2	10.67	13	12	
Means	6.22[a] (± 1.88)	26.56[a] (± 3.83)	19.28[a] (± 3.64)	28.72[a] (± 15.76)	

Means followed by different letters are significantly different ± *SE*

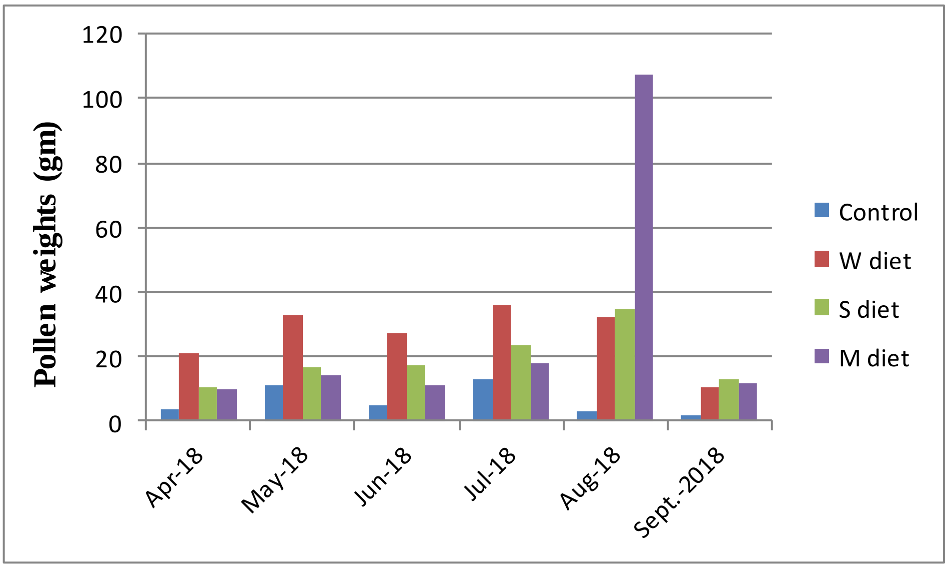

Figure 6: Pollen weights (gm) collected by honey bee colonies fed on examined diets confronted with unfed control colonies.

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