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Sesame *Sesamum indicum* L. (Pedaliaceae): Foraging Behavior of Honeybees *Apis mellifera* L. and Physicochemical Properties of Honey

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ABSTRACT

A study of foraging behavior of honeybees, *Apis mellifera* L. on sesame, *Sesamum indicum* L. (Pedaliaceae) was conducted in Motobes district, Kafrelsheikh Province during July-August of 2016 and 2017. Also, the study aimed to ivestigate the foraging behavior of honeybees on sesame flowers and the physicochemical characteristics and mineral contents of sesame honey were determined. Sesame plants start to bloom in the 1^{st} week of July and continues until the end of August during the two seasons. Workers of honeybees started to forage on sesame flowers after 0600 hrs, gradually increased until formed peak at 0900 and 1000 hrs, then gradually decreased and ceased at 1800 hrs. The maximum amounts of trapped sesame pollen/colony/hr were recorded at 0900 and1000 hrs. Sesame honey was characterized by high contents of fructose, glucose, maltose, K, Na, Ca, and P. It can be concluded that beekeepers can obtain good honey yield and/or trapped pollen loads from sesame during July and August. The component of sesame honey was found to be within the range of the required standards according to the international regulations of quality.

Keywords: Foraging, honey, honeybees, minerals, *Sesamum indicum*

INTRODUCTION

Sesame (*Sesamum indicum* L.), which originated in Africa, is cultivated in many parts of the world. About 90% of the planted areas cultivate in Africa and Asia (Beltrão and Vieira, 2001). Currently, China, India, and Burma are the world's largest producers of sesame, followed by Sudan, Nigeria, Pakistan, Bangladesh, Ethiopia, Thailand, Turkey and Mexico (Desai, 2004). In Egypt, sesame is grown in summer season (Taha *et al*., 2018a). Sesame flower produces nectar in a nectary disk surrounding the ovary and in a couple of extra floral nectaries on both sides of the pedicel (Free, 1993). Anthesis occurs early in the morning and senescence can continue 6 to 12 hrs, depending up on the variety and environmental conditions (Free, 1993). It is cultivated in considerable areas (29332.00 ha) in scattered locations throughout Egypt (Anon., 2016).

Foraging behavior of honeybees (*Apis mellifera* L.) have been studied on several crops including alfalfa (Taha *et al*., 2016; Al-Kahtani, *et al*., 2017), anise and caraway (Abo-Lila and Sadek, 1998), banana (Taha, 2007), carrot (Munir and Aslam, 2002), coriander (Bendifallah *et al*., 2013), Egyptian clover and faba bean (Shawer, 1987), loofah (Taha *et al*., 2006), okra (Hasnat *et al*., 2015), onion (Yucel and Duman, 2005), summer seed water melon (Taha and Bayomi, 2009).

The main honeys in Egypt are Egyptian clover, citrus, and cotton (Taha, 2000; Taha, 2005; Taha *et al*., 2018a). Besides, two secondary honeys: loofah (Taha *et al*., 2006), and banana (Taha, 2007) were reported in Kafrelsheikh province. Sesame plants bloom in July and August (Taha *et al*., 2018a). Honeybees visit sesame flowers to collect nectar and pollen (Danaka *et* al., 1990; Taha *et al*., 2018a).

Very few data are available on the activity of honeybees (*A. mellifera carnica* Pollmann) on sesame flowers and characteristics of sesame honey. The aim of this study is to determine the foraging behavior of honeybees on sesame flowers and to evaluate the physicochemical characteristics and mineral contents in sesame honey.

MATERIALS AND METHODS

Materials:

This investigation was conducted on sesame (*Sesamum indicum* L.) farm (10 ha) in Motobes district, Kafrelsheikh Province, Egypt during July and August (the blooming period of sesame) at 2016 and 2017 seasons. An apiary consisted of 100 colonies was located near the experimental farm at distance about 100 m.

Ten colonies (each had about 20000 bees) of hybrid Carniolan (*A. mellifera carnica* Pollmann) honeybees were selected to study the foraging behavior of honeybees for pollen collection. The selected colonies were equaled to be in the same strength (adult bees, brood and stored food). The queens of the experimental colonies were replaced by young open mated sister queens. The colonies were provided with pollen traps with efficiency of 25% at the peak of emblossoming for three weeks. The trapped pollen loads were collected hourly from 0600-1800 hrs and then weighted. The number of foraging bees/m^2/min were counted hourly at the same times. Mean weight of one pollen load was determined.

Methods:

Honey sampling

By the end of sesame flowering season, ten honey samples (each consists of 300 g) were harvested directly from capped honeycombs. Honey samples were filtered using a very narrow cloth refinery, packaged in 0.5 kg capacity sterile plastic containers, and kept at −21◦C until analysis to determine the physicochemical characteristics of honey at the central laboratory of Kafrelsheikh University in Kafrelsheikh, Egypt.

Physical characteristics

Specific gravity was determined according to Wedmore (1955), viscosity was measured by using viscometer at 29°C (Munro, 1943), electrical conductivity (EC) by utilization of "HANNA" Electro-conductivity and expressed in mS/cm (Vorwohl, 1964). Hydroxy methyl furfural (HMF) was determined using a colorimetric method developed by Meyav and Berk (1978). Granulation values were calculated as glucose to fructose (G/F), and as glucose to water (G/W) ratios (Taha and El-Sanat, 2007).

Chemical characteristics

Moisture content was estimated using dry matter content method; dry matter was determined by drying a sample of 2 g honey at 105°C to a constant weight. Total soluble solid and total carbohydrates were determined using the methods described in AOAC (2000). A sample of 0.07 g was used to determine the nitrogen by the micro-Kjeldahl method (AOAC, 2000), and the 6.25 factor was used to convert nitrogen into crude protein. Free acidity was determined according to White *et al*. (1962). The pH value was examined using glass rod “Hanna” pH-meter (AOAC, 2000).

Sugar determinations

Reducing sugars were estimated according to the methods described in AOAC (2000). The sugars (fructose, glucose, maltose and sucrose) were determined using the HPLC chromatographic method according to AOAC (2000). Glycemic index (F/G) of honey was calculated.

Ash and minerals determination

Ash determination was done by incinerating a sample of 2.00 g in an electric oven at 550°C until a constant of weight. A sample of 1.00 g was digested to determine the content of minerals. Wet digestion with nitric acid following the method of AOAC (2000) was used for determination the mineral content. Potassium (K), sodium (Na), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) contents were determined by using an Atomic absorption spectrophotometer (GBC Avanta E, Ser. No. A5616). The optimum working range for aforementioned elements is 2.0-580, 0.04-380, 0.20-760, 0.02-20, 0.60-2700, 0.20-27, 0.10-1000 and 0.20-1700 mg/kg, respectively. Phosphorus (P) was determined by using of a UV-VIS Spectrophotometer (UV-2550 Shimadzu, Ser. No. A108447). All determinations of the experiment were carried out in triplicate.

Statistical analysis

Data were subjected to the one-way analysis of variance (ANOVA) using SAS® software computer program (SAS, 2003). Means of foraging activity were compared by Duncan’s Multiple Range Test (Duncan, 1955).

RESULTS AND DISCUSSION

1-Phenology of flowering

Sesame plants start to bloom in the 1st week of July and continues until the end of August. One flower is produced at the axil of each leaf. The lower flowers usually begin blooming about two months after seeding, and blooming continues until the uppermost flowers are open. All flowers are bisexual. The total number of flowers/plant are about 77.55 and 78.66 flowers, and per m^2 are 3695.00 and 3747.89 flowers at the whole period of the flowering during seasons 2016 and 2017, respectively. The colour of pollen loads is white and mean weight of one load averaged 5.58 mg (Table 1).

Table 1. Phenology of flowering of sesame.

Items	Blooming period		Total number of flowers		Pollen load	
	Starting	Ending	Plant	m^2	Weight (mg)	Color
2016	3 July	31 Aug.	77.55±0.70	3695.00 ±160.79	5.58±0.08	White
2017	1 July	31 Aug.	78.66±0.76	3747.89 ±168.79	5.60±0.07	White

2- Honeybee foraging activity

Statistical analysis of data show that the activity of honeybees on sesame flowers was significantly (P<0.01) varied and depending on the time of the day. Workers started to forage on flowers after 0600 hrs, gradually increased until 0900 hrs, then gradually decreased and ceased at 1800 hrs when all flowers became closed. The maximum number of bees/m^2/min (20.75 and 21.45 bees) were recorded at 0900 hrs, followed by 20.55 and 20.93 bees/m^2/min at 1000 hrs during seasons 2016 and 2017, respectively (Fig. 1 and 2). This may be due to copious of nectar flow in the sesame flowers especially in the morning period; there after the nectar secretion gradually diminishes. These results were confirmed by Mahfouz *et al*. (2012) as they found the maximum number of *A. mellifera* on sesame flower was observed during 0900-1100 hrs and decreased with time during the day. The peaks of activity of honeybees on forage plants were varied, e.g. the maximum activity of honeybees on maize occurred at 0800-1000 hrs (Shawer, 1987), summer seed watermelon at 0900-1000 hrs (Taha and Bayoumi, 2009), okra at 0900-1100 hrs (Hasnat *et al*., 2015), loofah at 1200-1300 hrs (Taha *et al*., 2006), wild mustard, yellow sweet clover and Egyptian clover at 1200-1400 hrs (Shawer, 1987), broad bean at 1400-1600 hrs (Shawer, 1987), and alfalfa at 1700-1800 hrs (Taha *et al*., 2016).

The largest amounts of trapped sesame pollen/colony/hr (12.55 and 12.67 g/colony/hr) were recorded at 0900 hrs, followed by 12.14 and 12.22 g/colony/hr at 1000 hrs in 2016 and 2017, respectively (Fig. 1 and 2). Previous studies showed that, the largest amount of trapped pollen/colony/hr was recorded at 0800-0900 hrs for alfalfa (Taha *et al*., 2016), at 0900-1000 hrs for summer seed watermelon (Taha and Bayoumi, 2009), at 1200-1300 hrs for loofah (Taha *et al*., 2006).

3- Physical characteristics

The results given in Table (2) indicate that the values of specific gravity and viscosity were 1.42 and 86.42 poise, respectively. These values were higher than those of Egyptian clover honey (Taha and El-Sanat, 2007). Specific gravity and viscosity of honey were significantly positively correlated with total solid, but significantly negatively correlated with moisture content (Taha and El-Sanat, 2007).

The value of HMF (7.55 mg/kg) was within the acceptable range (≤40 mg/kg) of Codex Alimentarius (2001). On contrast, EC (1.67 mS/cm) was higher than two folded of the maximum value (0.8 mS/cm) of the required standards according to the international regulations of quality (Codex Alimentarius, 2001). The values of EC and HMF of sesame honey were lower than those of Egyptian clover honey (Taha and El-Sanat, 2007), Egyptian sider honey (El Sohaimy *et al*., 2015), Moroccan *Citrus* sp., *Eucalyptus* sp., *Lythrum* sp. and Umbelliferae honeys (Terrab *et al*., 2003b) and Tunisian eucalyptus, horehound, mint, orange, rosemary and thyme honeys (Boussaid *et al*., 2014).

The values of granulation of sesame honey as G/F ratio (0.75), and as G/W ratio (1.68) were lower than the values of Egyptian clover honey (Taha and El-Sanat, 2007), Moroccan *Citrus* sp., *Eucalyptus* sp., *Lythrum* sp. and

Umbelliferae honeys (Terrab *et al*., 2003b) and Emirates honeys (Habib *et al*., 2014). The actual proportion of G/F in any particular honey depends largely on the origin of the nectar (Anklam, 1998). The G/F and G/W ratios can used as indicators for honey quality (Oddo and Piro, 2004). The G/F ratio indicates the ability of honey to granulate (Taha and El-Sanat, 2007; Amir *et al*., 2010). Honey granulates faster when G/F ratio is more 1.0 and it slower when this ratio is less than 1.0 (Draiaia *et al*., 2015). The G/W ratio is considered an appropriate indicator for the prediction of honey granulation. The granulation is faster or completely when G/W ratio is more than 2.0 (Manikis and Thrasivoulou, 2001). Our results indicated that, sesame honey has lowest ability to granulation.

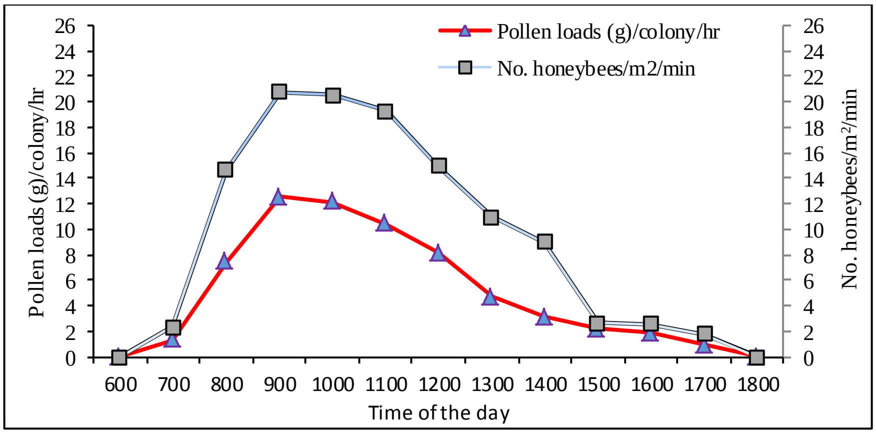

Figure 1. Honeybee foraging activity on sesame in relation to time of the day in 2016 season.

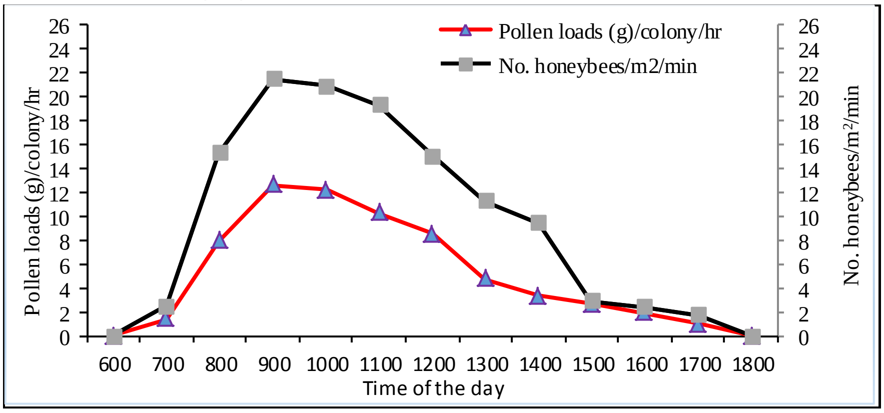

Figure 2. Honeybee foraging activity on sesame in relation to time of the day in 2017 season.

Table 2. Physicochemical characteristics of sesame honey.

Chemical characteristics		Physical characteristics	
Moisture %	17.70	Specific gravity	1.42
Total solid (%)	82.30	Viscosity (poise)	86.40
Total soluble solid (%)	81.09	HMF (mg/kg)	7.55
Total carbohydrates (%)	81.48	EC (mS/cm)	1.67
Estimated reducing sugars %	69.01	Granulation G/W	1.68
Fructose %	39.36	Granulation G/ F	0.75
Glucose %	29.65		
Sucrose %	2.64		
Maltose %	9.34		
Ash %	0.17		
Protein %	0.40		
Fats %	0.25		
Total polyphenol %	0.07		
F/G	1.33		
pH	4.62		
Acidity (mmol/kg)	31.24		

G= Glucose, F=Fructose, W=Water

4- Chemical characteristics

Data presented in Table (2) show that, moisture content (17.70%) was within the acceptable range (≤20%) of Codex Alimentarius (2001). Moisture content in sesame honey was in the range of Egyptian clover honey (Taha and El-Sanat, 2007), Egyptian sider honey (El Sohaimy *et al*., 2015), Emirates honeys (Habib *et al*., 2014), Moroccan honeys (Terrab *et al*., 2003b; Chakir *et al*., 2011), Spanish honeys (Pérez-Arquillué,, 1995; Terrab *et al*., 2004), and Yemeni honeys (El Sohaimy *et al*., 2015). Our moisture value was higher than the values of Nigerian honeys (Buba *et al*., 2013), Pakistani honeys (Fahim *et al*., 2014), Kashmiri honeys (El Sohaimy *et al*., 2015), Saudi honeys (El Sohaimy *et al*., 2015; Al-Ghamdi *et al*., 2017) and Tunisian rosemary honey (Boussaid *et al*., 2014). On contrast, sesame moisture value was lower than values of Tunisian eucalyptus, horehound, mint, orange, and thyme honeys (Boussaid *et al*., 2014). Moisture content in honey mainly depends up on the relative humidity and air temperature in the geographical origin throughout honey producing period (Crane, 1979). In addition, the variations of moisture content in honeys correlated to the content of solid materials in honey. Significant negative correlation between moisture content and each of sugars, ash, protein and total phenols (Taha and El-Sanat, 2007). The importance of moisture content in honey due to its role of granulation and fermentation during storage (Singh and Bath, 1997). Low moisture content in honey helps to promote longer life (Terrab *et al*., 2003a).

The concentrations of fructose (39.36%) and glucose (29.65%) were within the range (>60%) of the required standards according to the international regulations of quality (Codex Alimentarius, 2001). Relatively similar values were found in Egyptian sider honey (El Sohaimy *et al*., 2015), Moroccan *Citrus* sp., *Eucalyptus* sp., *Lythrum* sp. and Umbelliferae honeys (Terrab *et al*., 2003b) and Saudi honey (Al-Ghamdi *et al*., 2017). Our values were lower than the values in Egyptian clover honey (Taha and El-Sanat, 2007) and Saudi honey (El Sohaimy *et al*., 2015), but higher than the values in Yemeni honey (El Sohaimy *et al*., 2015) and Emirates honeys (Habib *et al*., 2014). The superiority of fructose compared to glucose in honey confirmed the high quality of sesame honey.

The concentrations of sucrose (2.64%) was within the acceptable range (≤5%) of Codex Alimentarius (2001). Relatively similar values were found in Egyptian clover honey (Taha and El-Sanat, 2007), Moroccan *citrus* sp. honey (Terrab *et al*., 2003b). Sucrose content in sesame honey was higher than that of Moroccan *Eucalyptus* sp., *Lythrum* sp. and Umbelliferae honeys (Terrab *et al*., 2003b). In contrast, our sucrose value was lower than the values of Egyptian sider honey (El Sohaimy *et al*., 2015), Pakistani honey (Iftikhar *et al*., 2011) and Saudi honey (Al-Ghamdi *et al*., 2017). High value of maltose (9.34 %) content was found in sesame honey. This value was higher than the values of Moroccan *Citrus* sp., *Eucalyptus* sp., *Lythrum* sp. and Umbelliferae honeys (Terrab *et al*., 2003b) and Egyptian clover honey (Taha and El-Sanat, 2007).

Very low values of protein (0.40%), fat (0.25) and ash (0.17%) content in sesame honey were found. These values were within the range of Brazilian honeys (Azenedo *et al*., 2003), Egyptian clover honey (Taha and El-Sanat, 2007), Egyptian sider honey (El Sohaimy *et al*., 2015), Emirates honeys (Habib *et al*., 2014) and Tunisian honeys (Boussaid *et al*., 2014). Our values were lower than protein and ash values of Kashmiri honey (El Sohaimy *et al*., 2015) and Nigerian honeys (Ndife *et al*., 2014). The variations of ash and protein content in honey may be related to the amount (Taha and El-Sanat, 2007) and the origin (Taha, 2015; Taha *et al*., 2018b) of the pollen content in the honey.

The pH values (4.62) and Acidity (31.24 mmol/kg) of sesame honey were within the acceptable range [(pH 3.40-6.10) and (≤50 mmol/kg), respectively] of Codex Alimentarius (2001). Sesame pH value was higher than the values of Saudi honey (Al-Ghamdi *et al*., 2017), Pakstani *Ziziphus* sp. and *Brassica* sp. honeys (Naheed and Farooqi, 2018), but lower than the values of Moroccan honeys (Terrab *et al*., 2003b), Pakistani honey (Iftikhar *et al*., 2011), Nigerian honeys (Ndife *et al*., 2014), Emirates honeys (Habib *et al*., 2014), Tunisian honeys (Boussaid *et al*., 2014) and Pakstani *Acacia* sp. honey (Naheed and Farooqi, 2018). The high acidity of honey correlates with the fermentation of honey sugars into organic acid, which is responsible for flavour and stability against microbial deterioration (Bogdanov *et al*., 2008).

As shown in Table (3) sesame honey had high levels of K (695.53 mg/kg), Ca (515.12 mg/kg), Na (189.50 mg/kg), P (155.44 mg/kg), while the elements of Zn (1.61 mg/kg), Mn (1.24 mg/kg), and Cu (0.15 mg/kg) were present in traces. Our values were in the ranges of Canary Islands honey (Hernández *et al*., 2005), Egyptian clover honey (Taha *et al*., 2010), Spanish honeys (Terrab *et al*., 2004) and imported Australian, German, Malaysian, New Zealand, and Yemeni honeys (Alqarni *et al*., 2014). Our mineral values were higher than values of Nigerian honeys (Ndife *et al*., 2014). On contrast, the ranges of Mg, Fe, Mn and Zn were lower than the ranges of honeys imported from Australia, Egypt, Germany, Malaysia, New Zealand, Saudi Arabia, Yemen (Alqarni *et al*., 2014).

Table 3. Amounts (mg/kg) of mineral contents of sesame honey.

Element	K	Ca	Na	P	Mg	Fe	Zn	Mn	Cu
Concentration	695.53	515.12	189.50	155.44	75.47	12.23	1.61	1.24	0.15

Potassium was the most prevalent mineral in sesame honey and determined as 42.25% of the total mineral quantified in honey, followed by Ca (31.29%), Na (11.51%), and P (9.44%). Our results are in harmony with those obtained by Taha *et al*. (2010) for Egyptian clover honey, Ördög *et al*. (2017) for Hungarian black locust, rape and sunflower honeys, Terrab *et al*. (2003b) for Moroccan *Eucalyptus* sp., *Lythrum* sp. and Umbelliferae honeys, Terrab *et al*. (2004) for Spanish thyme honey, Alda-Garcilope *et al*. (2012) for Spanish avocado, mountain range and thyme honeys, Ndife *et al*. (2014) for Nigerian honeys, and Uršulin-Trstenjak *et al*. (2015) for black locust Croatian honey.

The elements of Zn (0.10%), Mn (0.07%), and Cu (0.01%) in sesame honey were present in traces. Similar values were found in Moroccan *Eucalyptus* sp., *Lythrum* sp. and Umbelliferae honeys (Terrab *et al*., 2003b), Egyptian clover honey (Taha *et al*., 2010) and alfalfa Saudi honey (Taha *et al*., 2017) for Zn and Mn. In contrary, the Cu element was not find in Egyptian honey (Badei and Shawer, 1986; Taha *et al*., 2010).

Based on the present data, it can be concluded that a peak of foraging for nectar and pollen were recorded at 0900-1000 hrs. Beekeepers can obtain good honey yield and/or trapped pollen loads from sesame during July and August. The sesame honey was mostly of good quality according to Codex Alimentarius (2001). Sesame honey was characterized by high contents of high values of fructose, glucose, maltose, protein, fats, ash, K, Na, Ca, and P.

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السمسم (العائلة البيدالية): سلوك سروح نحل العسل والخواص الطبيعية الكيميائية للعسل

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أجريت دراسة حول سلوك نحل العسل على السمسم خلال شهري يوليو وأغسطس من عام 2016 وعام 2017. وتهدف الدراسة أيضا إلى فحص سلوك سروح نحل العسل على زهور السمسم وتحديد الخصائص الطبيعية الكيميائية ومحتويات المعادن في عسل السمسم. وأظهرت النتائج أن نباتات السمسم تبدأ في التزهير في الأسبوع الأول من شهر يوليو وتستمر حتى نهاية شهر أغسطس. وتبدأ شغالات النحل بالسروح على زهور السمسم بعد الساعة السادسة صباحا، ويزداد عدد النحل السارح تدريجياً حتى يبلغ ذروته في الساعة التاسعة والعاشرة صباحاً، ثم ينخفض تدريجياً إلى أن يتوقف عند الساعة السادسة مساءً. وتم تسجيل أكبر كمية من حبوب اللقاح المجموعة / طائفة خلال الساعة التاسعة والعاشرة صباحاً. ويتصف عسل السمسم بمحتويات علية من الفركتوز والجلوكوز والمالتوز، والبوتاسيوم، والصوديوم، والكالسيوم، والفوسفور. ويستطيع مربوا النحل أن يحصلوا على محصول جيد من العسل و/أو حبوب اللقاح من السمسم خلال شهري يوليو وأغسطس. وأظهر تحليل عسل السمسم أنه في نطاق المعايير المطلوبة وفقا للمعايير الدولية للجودة.