Effect of Host Diet on the Immature Developmental Time, Fecundity, Sex Ratio, Adult Longevity, and Size of *Apanteles galleriae* (Hymenoptera: Braconidae)

FEVZI UÇKAN[1] AND EKREM ERGİN

Department of Biology, Faculty of Science-Art, Balıkesir University, Balıkesir, 10100, Turkey

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ABSTRACT The effect of host diet on the immature developmental time, fecundity, sex ratio, adult longevity, and size of *Apanteles galleriae* Wilkinson, a koinobiont, solitary, and early instar larval endoparasitoid of the lesser wax moth, *Achroia grisella* (F.), was investigated. All experiments related to the effect of diet were conducted at 25 ± 1°C, 60 ± 5% RH, and a photoperiod of 12:12 (L:D) h. The experiments were conducted by supplying hosts with three types of natural food (blackened, dark yellowish, and pure comb). The change in the type of host diet from blackened, to yellowish, and to pure comb prolonged immature developmental time, shortened the life span, increased sex ratio in favor of males, and reduced fertility and adult size of parasitoid species. The first adult eclosion occurred at 25, 30, and 52 d for males and 27, 33, and 54 d for females, with blackened, dark yellowish, and pure comb, respectively. The mean production of progeny per female parasitoid for each diet was 105.09, 45.49, and 0.46 (n = 30). Males lived an average of 43.46, 14.52, and 5.75 d and females lived an average of 40.86, 16.8, and 10 d in relation to host diet changes. Parasitoid length varied considerably with 2.84, 2.5, 2.2 mm, and 2.51, 2.27, 1.94 mm for females and males, respectively. Of the three kinds of natural food, the first was determined to be the most optimal diet for the parasitoid species.

KEY WORDS *Apanteles galleriae*, food quality, immature development, fecundity–sex ratio, longevity, adult size

IN ADDITION TO environmental factors such as temperature, light, and humidity (Melton and Browning 1986, Mendel et al. 1987), the larval development of parasitoid species is considerably affected by several factors depending on the host itself (Kansu and Uğur 1984, Hirashima et al. 1990, Petitt and Wietlisbach 1993, Tillman et al. 1993). The quantity and quality of the food sources provided by the host have an impact on both immature stages of development and some physiological activities of adults. By and large, the host species allowing a parasitoid species to develop into maturity is considered nutritionally suitable for that parasitoid species (Gülel 1988). It has been reported that quantitative food inadequacy and changes in the quality of natural nutrients during larval developmental period of parasitoid species affect developmental time, adult size, longevity, fecundity, and sex ratio in progeny. (Gülel 1988, 1991; Hagley and Barber 1992; Tillman and Cate 1993). The studies conducted on artificial diets to determine the nutritional needs of parasitoids are not always efficient because of low nutritional quality and contamination during preparatory methods (Gülel 1991). On the contrary, the importance of host feeding and natural food supplied to parasitoids by host species that is related to the long lasting host parasitoid interactions still maintain its validity and reliability.

Apanteles galleriae Wilkinson is a koinobiont, solitary, and early instar larval endoparasitoid of Lepidopterous species that can cause significant damage to comb in honey bee hives. It has been formerly introduced as a biological control agent and some of its biological characteristics have been reported (Shimamori 1987, Uçkan and Gülel 2000). Because the physiological interactions between host and parasitoid species form the basis for biological control applications, the success rate is closely related to how much we know about them. Therefore, in this study, we compared developmental time, fecundity, sex ratio, adult longevity and size of *A. galleriae* when the host species were given three different natural food types found in hives. We aimed to show the most available rearing and maintaining conditions of *A. galleriae* in mass production and biological control applications.

Materials and Methods

We used koinobiont, solitary and early instar larval parasitoid *Apanteles galleriae* and early instar larvae of lesser wax moth, *Achroia grisella* (F.), as parasitoid and host species, respectively, in the experiments. All host exposures, parasitoid rearing, and experiments related

[1] E-mail: uckanf@balikesir.edu.tr.

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Table 1. Effect of host diet on the fecundity and sex ratio of *A. galleriae*

Food type	*n*	Offspring sex	Fecundity of parasitoids		Female sex ratio (%)	Adult parasitoid/ female
			Range	Mean ± SD		
Blackened comb	30	F	94–129	106.26 ± 9.55a	50.55	
		M	78–124	103.93 ± 13.79a		105.09x
Dark yellowish comb	30	F	25–51	37.33 ± 6.01b	41.02	
		M	37–66	53.66 ± 6.87c		45.49y
Pure comb	30	F	0–1	0.13 ± 0.35d	13.97	
		M	0–2	0.80 ± 0.68e		0.46z

Means in the same column and line followed by the same letter are not significantly different ($P > 0.05$). *n*, number of female parasitoids.

to the effects of host food type were conducted in a rearing room at 25 ± 1°C, 60 ± 5% RH, and a photoperiod of 12:12 (L:D) h. The methods to establish and maintain successive cultures of both host and parasitoid species are described by Uçkan and Gülel (2000).

Studies on the effect of host diet on the developmental time, fecundity, sex ratio, adult longevity, and size of *A. galleriae* were made by exposing early instars of host species to three main types of comb that can be found in bee hives: (1) Blackened comb; which is kept for a long period in the hive to feed bees or used again and again until it turns dark black. (2) Dark yellowish comb; which is kept for a lesser period in the hive and turns brownish yellow. (3) Pure comb; which is prepared by melting wax, and is sold to use in young or old hives for rapid honey production. All experimental results will be given in this order of natural food unless stated otherwise. Two pairs of *A. galleriae* adults (two females, 2 males) were placed in five 500-ml jars each containing early instars of *A. grisella* (obtained from two females) for each type of diet and sealed with cloth tied around their necks. All jars were observed daily until the emergence of adults for each diet. The total number of progeny per female and sex ratio of progeny were determined. Experiments were repeated three times with specimen taken from different populations at different times. The jars containing pure comb were kept under the same laboratory conditions for six months to determine whether or not there would be adult emergence.

Longevity of newly emerged adult female and male *A. galleriae* for the first and second food type was measured by placing an individual pair in five 250-ml jars each containing a piece of cotton ball soaked with 50% honey solution. Food supplement was replenished at 2-d intervals until all parasitoids died and their longevity was recorded. All experiments were repeated three times with specimen taken from different population at different times. Because fecundity was very low on pure comb, experiments related to longevity could only be conducted with two females and 12 male parasitoids.

To determine the effect of diet on adult size, random samples (25 females, 25 males) from cultures of the first two different food types were used to obtain measurements of adult size. The measurements could only be obtained from two females and 12 males for the pure comb. Measurements were made from the head to the tip of the abdomen using a stereobinuclear microscope with a calibrated eyepiece micrometer.

Data were subjected to analysis of variance, and the difference between means was tested using least significance difference ($P < 0.05$).

Results

Natural food type of host species affected the immature developmental time of parasitoid species. Adult eclosion occurred at 25, 30, and 52 d for males and 27, 33, and 54 d for females with three types of diet, respectively. Table 1 shows the result of experiments related to the effect of host diet on the fecundity and sex ratio of *A. galleriae* adults. The type of host diet considerably changed the sex ratio of parasitoids in progeny. It, also, affected the number of adult parasitoids in progeny per female. The mean number of progeny produced by a single female throughout its adult life was 105.09 when host species was fed on blackened comb. The mean fecundity was 45.49 and 0.46 with dark yellowish and pure comb, respectively. The differences were significant ($P < 0.05$). The sex ratio of adults was slightly in favor of females (50.55%) with blackened comb, it became considerably male-biased with the second and third kind of natural food (41.02 and 13.97%) (Table 1).

The longevity of male and female adults as a function of host diet is given in Table 2. Both sexes lived longer when the host species was provided blackened comb. Longevity of males ranged from 31 to 54 d for those provided blackened comb, 9–24 d for those provided dark yellowish comb, and 1–14 d for those provided pure comb. Females lived within a range of 21–61, 10–34, and 8–12 d for three kinds of diet, respectively. The mean longevity of adult male and female was 43.46 and 40.86 d, respectively, when host species was fed on blackened comb. The difference between the longevity of sexes was not significant

Table 2. Effect of host diet on the adult longevity of *A. galleriae*

Food type	*n*	Sex	Adult longevity (days)	
			Range	Mean ± SD
Blackened comb	15	F	21–61	40.86 ± 10.26a
	15	M	31–54	43.46 ± 6.68a
Dark yellowish comb	15	F	10–34	16.8 ± 6.08b
	15	M	9–24	14.52 ± 3.7c
Pure comb	2	F	8–12	10.0 ± 2.83d
	12	M	1–14	5.75 ± 4.35e

Means in the same column followed by the same letter are not significantly different ($P > 0.05$). *n*, number of parasitoids.

Table 3. Effect of host diet on the adult size (mean ± SD) of *A. galleriae*

Food type	*n*	Adult size, mm	
		Female	Male
Blackened comb	50	2.84 ± 0.10a	2.51 ± 0.18a_1
Dark yellowish comb	50	2.5 ± 0.12b	2.27 ± 0.21b_1
Pure comb	14	2.2 ± 0.14c	1.94 ± 0.12c_1

Means in the same column and line followed by the same letter are not significantly different ($P > 0.05$). *n*, number of parasitoids.

($P > 0.05$). The mean longevity of adults considerably declined to 14.52 and 16.8 d for males and females, respectively, with dark yellowish comb. But, the difference between sexes was significant ($P < 0.05$). When host species was provided with pure honey, the mean longevity declined again and males lived an average of 5.75 d, whereas females lived 10 d. Males lived slightly longer than females when host species provided with blackened comb. But, females lived significantly longer than males with the other types of host diet ($P < 0.05$) (Table 2).

Adult size of *A. galleriae* males and females showed variances in accordance with host diet and decreased from an average of 2.68–2.07 mm (Table 3). The longest adults were obtained from the first experimental group as 2.51 and 2.84 mm for males and females. The change in host diet resulted in lessening of males and females in size. Parasitoid average length was 2.27 and 2.5 mm and 1.94 and 2.2 mm when host species fed dark yellowish and pure comb, for males and females, respectively. The differences among experimental groups were significant for both sexes ($P < 0.05$).

Both parasitized and nonparasitized host larvae were observed in jars containing pure comb after storing them for 6 mo in the laboratory, however, they could neither complete their larval stages nor pupate.

Discussion

Not only the quantity but also the quality of natural food sources is an important factor for the growth and development of all living beings (Eischen and Dietz 1987; Gülel 1988, 1991; Hagley and Barber 1992). It has been reported that the content of the diet supplied during larval developmental period significantly affects the living and development of larvae (Eischen and Dietz 1987). In this study, the period from egg to adult for both sexes of *A. galleriae* changed according to the diet of the host on which the parasitoid completed its immature development. Development time of females was greater than of males on all host diet. The number of days from oviposition to first emergence of adults was 25 and 27 d for males and females, respectively, with blackened comb. Changing host diet resulted in a decrease in the rate of adult emergence. It was on the 30th and 33rd days for the second diet and lasted for 52 and 54 d for the third one, for males and females, respectively. Therefore, it can be concluded that the quality of host diet is the determining factor for both host and parasitoid development. The decrease in the rate of larval development of host species due to diet changes reduced fecundity as well as larval development of parasitoid species. We obtained the highest reproductive capacity per female when the host species was provided with blackened comb. The total production of progeny per female decreased with the second diet. There was a considerable decrease in the fecundity with pure comb and we could not obtain any progeny from most of the female adults (Table 1). Probably, this situation resulted from undevelopment of most of host larvae due to the quality of host diet. Host diet-related changes in the total production of progeny by *A. galleriae* have also been reported to occur with other parasitoid species, too (Gülel 1988, 1991; Hagley and Barber 1992). We also obtained an increase in the ratio of males in progeny with respect to food type (Table 1). The sex ratio of adults was 1:1.02 in favor of females when the host species was provided with blackened comb. Male progeny outnumbered females with the second and third type of food, and the ratio was 1.44:1 and 6.16:1, respectively. Our results are in conformity with the results of experiments carried on other species, *Pholetesor ornigis* (Weed) (Hagley and Barber 1992), *Pimpla turionellae* L. (Kansu and Uğur 1984), and *Bracon mellitor* Say (Tillman and Cate 1993), but not with *D. boarmiae* (Walker) (Gülel 1988). The fact that this species is a gregarious ectoparasitoid can suggest an explanation for the situation.

An interaction between parental feeding strategy and adult life span has been reported for insects (Gülel 1982, Hawkins and Smith 1986, Ridgway and Mahr 1990, Hailemichael and Smith 1994). Along with natural food sources, the host species providing food for parasitoid species plays an important role in determining the longevity of adult parasitoids (Senrayan et al. 1988, Petitt and Wietlisbach 1993). Our results (Table 2) demonstrate that host diet considerably affects adult longevity of parasitoids. The decline in adult life span may result from the insufficient supply of the necessary materials from host or food source by parasitoids. It has also been evidenced by the studies carried on *D. boarmiae* (Gülel 1982), *P. ornigis* (Hagley and Barber 1992), *Anastasus semiflavidus* Gahan (Mendel et al. 1987), and *Xanthopimpla stemmator* (Thunberg) (Hailemichael and Smith 1994). The increase in the longevity in favor of females when food quality is low may be an important adaptation for the parasitoid species to maintain its generation because only a limited number of females are able to emerge. Parasitoid length differed markedly depending on host diet. The results of three experimental groups (Table 3) for both sexes were significantly different ($P < 0.05$). They were also in correlation with the results of other studies (Gülel 1988). The decline in the quality of natural food may again suggest an explanation for this shortage in length of adults as a result of inadequate food intake during immature development.

In conclusion, blackened comb is more efficient than dark yellowish. Pure comb did not appear to be a suitable diet for both host and parasitoid species. The

fact that there still were parasitized and nonparasitized larvae in cultures after 6 mo and they died before pupation is strong evidence for this conclusion. Nutritional insufficiency of pure comb influenced the host species so that no host larvae pupated or became adult. However, the same diet was sufficient enough to let a few parasitoid larvae complete their immature development. We hope that the results we obtained are beneficial for biological control applications and mass rearing of parasitoid species. Removing the blackened comb from the hives can help honey producers prevent the damage caused by *Galleria mellonella* L., *A. grisella* (F.), and *Achroia innotata* Walker to a certain extent. It would also be beneficial to make further studies concerning the analysis of the chemical composition of diets and their influence on the development of both host and parasitoid species.

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