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Life Tables of *Hermetia illucens* (Linnaeus, 1758) (Diptera: Stratiomyidae) on Different Foods

Bülent YAŞAR*[1] Tansu ÇİRİK[1]

[1] Isparta University of Applied Sciences, Faculty of Agricultural Sciences and Technologies, Department of Plant Protection, 32260, Isparta

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Abstract: In this study, the effects of different food types on life table parameters of *Hermetia illucens* (L.) (Diptera: Stratiomyidae) were investigated. Five different foods, namely Tomato, Banana, Yoghurt, Apple and Corn meals were put in 10 cm petri dishes separately and then 500 newly laid eggs were transferred into each petri dishes. Experiments with larvae were carried out at 25°C, 50% RH, and 16:8 L:D photoperiod. Temperature and humidity levels were switched to 29°C, and 60%, respectively after pupation to facilitate adult eclosion. According to results, the longest and the shortest development time of *H. illucens* from egg to adult were found on Yoghurt (77.67 days) and Corn flour (42.18 days), respectively. The highest mortality rate was found as 94.8% on Corn meal, while the lowest mortality rate was calculated as 65.8% on Banana. The highest number of eggs were recorded in the females feed on Banana (1426 eggs), and followed by the ones which feed on Yoghurt (1262 eggs), Corn meal (384) and apples (205 eggs). on the contrary, no eggs were obtained from the females which developed on Tomatoes life tables could only be constructed for the individuals which feeding on Banana and Yoghurt since females which developed on other food types did not lay any eggs. The difference between the intrinsic rate of increase (rm) on Banana and Yoghurt was found to be statistically nonsignificant ($p<0.05$). The intrinsic rate of increasing was the highest on Banana (0.022 females / female / day). The net production rate (Ro) was the highest (2.891 female / female / generation) on Banana, while its difference from Yoghurt was statistically nonsignificant ($p<0.05$).

Hermetia illucens (L.) (Diptera: Stratiomyidae)'in Farklı Besinler Üzerindeki Yaşam Çizelgeleri

Anahtar Kelimeler
Hermetia illucens,
Yaşam çizelgesi,
Kalıtsal üreme yeteneği,
Net üreme gücü

Özet: Bu çalışmada değişik besinlerin *Hermetia illucens* (L.) (Diptera: Stratiomyidae) üzerindeki etkileri araştırılmıştır. Çalışmada beş farklı besin (domates, muz, yoğurt, elma ve mısır unu) kullanılmıştır. Çalışmalar sonucunda, *H. illucens*'te en uzun gelişme süresi 77.67 gün yoğurtta, en kısa gelişme süresi ise 42.18 gün ile mısır ununda beslenenlerde bulunmuştur. Denemede kullanılan besinler arasında ergin öncesi dönemlerdeki en yüksek ölüm oranı %94.8 ile mısır unu ile beslenenlerde olurken en düşük ölüm oranı % 65.8 ile muzda saptanmıştır. Farklı besin çeşitlerinde beslenen *H. illucens*'in bıraktığı yumurta paketi ve yumurta sayısına bakıldığında en fazla muzda (8 yumurta paketinde 1426 adet) beslenenlerde elde edilmiş ve bunların açılma oranı da %89.7 olarak bulunmuştur. Yoğurt ile beslenen dişilerde ise 7 yumurta paketinde 1262 adet yumurta bırakılmış ve bunların açılma oranı %87.3 olmuştur. Mısır unu ve elma ile beslenenlerde ise bırakılan birer yumurta paketinde sırasıyla 384 ve 205 adet yumurta sayılmış; domateste beslenenler ise hiç yumurta bırakmamıştır. Yaşam çizelgeleri, bazı besinlerle beslenenlerin yumurta vermemesinden dolayı oluşturulamadığı için bu değerler sadece muz ve yoğurt için hesaplanabilmiştir. Kalıtsal üreme yetenekleri (rm) arasındaki fark istatistikî olarak önemsiz bulunmuştur ($p<0.05$). Kalıtsal üreme yeteneği en yüksek 0.022 dişi/dişi/gün olarak muzda bulunmuştur. Net üreme gücü (Ro) en yüksek 2.891 dişi/dişi/döl olarak muzda olmasına karşılık yoğurt ile arasındaki fark istatistikî olarak önemsiz bulunmuştur ($p<0.05$).

*Corresponding author: bulentyasar99@hotmail.com

1. Introduction

İt is a fact that recycling of organic waste will contribute to both the ecosystem and the economy of the country. Besides other strategies, *Hermetia illucens* (L.) (Diptera: Stratiomyidae) an insect species called Black Soldier fly, can be used for waste management and pollution reduction. Both research and production activities continue to benefit from this insect species all over the world. Larvae of *H. illucens* have been proven to be beneficial to the environment and to humans by recycling organic materials wast [1, 2] and by producing fertilizer. These; [3], the use of larvae as a source of protein and minerals in poultry [4-7], biodiesel production [8], the use of chitin in cosmetics industry, can be summarized as the elimination of some harmful bacteria and the inhibition of multiplication in house by laying eggs. Because of these reasons, interest in the production of this insect continues to increasing a day after day [9].

However, although there are only a few people involved in the production of this subject in our country, there is no scientifically relevant work. We believe that the disposal of the authorities should be taken in fighting against the house flies, which are important in the cultivation of some animals and in community health, which we have benefited from the assessment of organic wastes. But there are still a lot of things to say about the production of this insect.
But there are still a lot of things to say about the production of this insect. One of these is how the nutrients given to the insect affect it. This study is important in terms of the fact that life sciences studies applied against other insects have been preceded. In this study, information about the development and reproduction of the larvae grown with five different nutrients was obtained.

Hermetia illucens females after mating lays eggs with more than 500 dry solids near the edges of cracked organic matter or near cracks. Each egg is about 1 mm long and is creamy white in color. Once the *H. illucens* have laid their eggs, whatever they find as organic waste, they start consuming them immediately. The larvae can reach an average length of 27 mm [1]. It has been reported that larvae of *H. illucens* have a temperature of 28 °C and a rate of development of larvae in 60% RH is 18 days and that of pupae is 15 days [20].

2. Materials and Methods

Hermetia illucens was reared in insect rearing rooms in the Department of Plant Protection of the Faculty of Agriculture, Süleyman Demirel University. The insect cultures were started with the eggs left by the newly mated females. Restaurant waste was used in the production of stock culture.

During larval development, rearing room was set at 25°C, 50% RH, and 16:8 L:D photoperiod. When larvae matured, temperature and the RH of the rearing room were switched to 29±1°C, and 60 ± 5% RH. to facilitate adult eclosion.

The experiments were carried out in five pieces of 10-cm plastic petri dishes, each of which contained 2 grams of tomato, banana, yoghurt, apple or corn flour separately. A group of 500 eggs (replications) of *H. illucens* was transferred to each petri dishes containing one of the five food media. Because of the hiding of the larvae from the eggs in the food, the periods of each stage of larvae period could not be determined separately. However, when they migrated to become pupae, the total developmental periods of the larvae could be determined.

A filter paper was placed at the bottom of each petri dishes to prevent fungal development due to ambient humidity. The larvae grew in this environment until maturity, and then they were transferred into plastic containers with climbing ramps to enable larvae to climb out the feeding medium to pupate. Pupae formed in each petri dishes that contained different food types were taken to another rearing room which where they were supplied with an additional light intensity of 3200 lumen to allow adults to mate. Potted ornamental plants which served as mating and resting sites for adults were also placed in the rearing room. Perforated cardboard boxes have been hung up for the adults to lay their eggs.

Eggs released from the Petri cups were checked and counted every day. The experiments were continued until the last adult individual died. The total number of eggs left by females which developed on each of the five food types were determined.

The following formula was used in the calculation of life tables.

$$1 = \Sigma\,(-rm.x)\; lx.mx\;[10-12] \qquad (1)$$

In this formula;

lx = viability rates according to the starting level
mx = numbers of female individual left per day
e = logarithm base
r^m = the intrinsic rate of increase
x = female refers to the age of the individual in days.

Net Reproductive rate (Ro) is found by multiplying the daily values of lx and mx.

$$Ro = \Sigma\; lx.mx\;[10,13] \qquad (2)$$

The mean generation time (To) after this data was obtained;

$$To = LnRo - rm\;[10] \qquad (3)$$

The rm values obtained from the life tables were obtained using the Jack-knife method. This formula is given below.

$$J\,rmi = [rmt.n - rmij.(N-1)][14,15] \quad (4)$$

Population doubling time "DT";

$$DT = ln2 / rm\ [16] \quad (5)$$

and reproduction limit (λ) is calculated using this formula;

$$\lambda = erm\ [10] \quad (6)$$

The experiments were established according to randomized trial design. Tukey's HSD multiple range test (P≤0.05) was applied on the data about the developmental time obtained from the study after One-Way ANOVA test. A t-test (P≤0.05) was applied for comparing the averages of life table parameters, since there were only two food types which we obtained eggs on. The statistical analyzes used for the comparison of the averages were performed by using SPSS 23.0 package program. [17].

3. Results

When the developmental stages of *H. illucens* fed on five different food groups were examined, statistical analysis revealed that the difference between the food types in the egg period was not statistically significant (p<0.05) (Table 1). Regarding larvae, food types affected development time and in this respect, the difference between banana and corn flour was statistically nonsignificant (p<0.05), while there is no difference between apples, tomato and yoghurt (p<0.05). The difference between banana and corn flour was statistically nonsignificant (p<0.05) and the others significant (p<0.05). The longest and the shortest larval development were realized on yoghurt (62.37 days) and on banana (30.95 days), respectively. Adult lifespan was not affected by food types (p<0.05).

It was determined that pupal period took 13.25 and 12.30 days on yoghurt and tomato, respectively, while the shortest development duration of pupa was observed as 3.11 days on apple-fed larvae. When these results are taken into account, it is obvious that the food type has an effect on the development of pupal stages. When the mortality rates in immature stages of *H. illucens* fed on different food types were examined, mortality rates of egg stages could not be examined since experiments with larvae and pupae were established. The mortality rates during the larval stage have different values for different food types. In larval period, the highest mortality rate was observed on yoghurt (52%), while the least mortality rate was on banana (4.6%). In pupal period, the highest mortality rate was found on tomato with 73.6%, while the least mortality was found on yoghurt with 38.2% (Table 2).

Table 1. Duration of immature and adult stages of *Hermetia illucens* in different food groups

Stages	Foods				
	Banana	**Yoghurt**	**Corn flour**	**Tomato**	**Apple**
Egg	3.03 ± 0.02 a*	3.03 ± 0.02 a	3.07 ± 0.03 a	3.03 ± 0.02 a	3.04 ± 0.02 a
Larva	30.95 ± 0.53 d	62.37 ± 1.30 a	31.03 ± 0.70 d	35.89 ± 0.68 c	42.40 ± 0.81 b
Pupa	9.03 ± 0.49 b	13.25 ± 1.43 a	11.14 ± 0.76 b	12.30 ± 0.80 a	3.11 ± 0.36 c
Adult	5.31 ± 0.20 a	4.45 ± 0.21 b	4.33 ± 0.56 b	4.14 ± 0.46 b	4.50 ± 0.43 b

* Means (± standard error) followed by different letters within line are significantly different according to Tukey's HSD multiple range test (p≤0.05).

Table 2. The mortality rates in different development stages of *Hermetia illucens* (%)

Stages	Foods									
	n	**Banana**	**n**	**Yoghurt**	**n**	**Corn flour**	**n**	**Apple**	**n**	**Tomato**
Larvae	500	4.6	500	52	500	44.4	500	35	500	21
Pupae	477	61.2	240	38.2	278	50.4	325	59.6	395	73.6
Totaly		65.8		90.2		94.8		94.6		94.6

Table 3. The number of egg packs, eggs hatching rates and the number of eggs laid by females of *H. illucens*

Egg packages	Food types				
	Banana	**Yoghurt**	**Apple**	**Corn flour**	**Tomato**
1	164	610	205	384	-
2	120	100	-	-	-
3	234	112	-	-	-
4	155	95	-	-	-
5	135	97	-	-	-
6	177	92	-	-	-
7	218	155	-	-	-
8	223	-	-	-	-
Total	1426	1262	205	384	0
Egg hatching rate (%)	89.7	87.3	69.7	64.5	-

Table 4. Life table parameters of *Hermetia illucens* fed on different foods

	Life table parameters				
	r_m	R_o	T_o	GRR	λ
Banana	0.0221±0.0083 a*	2.8919±1.0488 a	48.0431±0.0001 a	8.456	1.022
Yoghurt	0.0110±0.0050 a	2.5250±0.9584 a	84.0028±0.0005 b	25.755	1.011
Corn flour	-	-	-	14.769	0.995
Apple	-	-	-	7.592	0.984
Tomato	-	-	-	0.000	0.000
P	1.2669	0.7991	0.000		
*	t-test P>0.05	t-test P>0.05	t-test P<0.05		

*Means within a different letters on the same column are statistically different (p≤0.05).

Among the foods used in the experiments, the highest mortality rate in immature stages was found on corn flour with 94.8% and the lowest on bananas (65.8%) (Table 2). When the sex ratios of *H. illucens* on different food types were examined, the highest ratio was found on bananas, followed yoghurt, corn flour, tomatoes, and apples.

When *H. illucens* females developed on different food types were compared in terms of egg packs, egg hatching ratios and egg numbers laid by the females, the highest number of egg packages were left by the females developed on banana (8 egg packages). The hatching ratio of banana feding group was found to be 89.7%. Yoghurt-fed group is the second regarding the number of egg package and hatching ratio. In the group fed with yoghurt, 7 egg packages were laid and the hatching ratio was 87.3%. In the groups fed on apple and corn flour, one egg package of each was laid and their hatching ratios were determined as 69.7% and 64.5%, respectively. No egg was laid in the group fed on tomato (Table 3).

When the intrinsic rate of increase (r_m) and net reproductive rate (R_o) values were examined, the difference between food groups was found to be statistically significant ($p<0.05$) (Table 4).

Life-table curves can not be created in single-packaged foods such as corn flour and apple-fed foods, or in foods where no eggs are laid, such as tomatoes. There are at least two data about egg counts in the calculation of the life table parameters. Therefore, in the present study, life tables were constructed only for groups fed on banana and on yoghurt that oviposited more than one egg package.

While the intrinsic rate of increase (r_m) was found to be highest on banana with 0.022, the difference between banana and yoghurt was found to be statistically nonsignificant ($p<0.05$). The net reproductive rate (R_o) was the highest on banana with 2.891. The difference between the net reproductive rate was found to be statistically nonsignificant between banana and yoghurt ($p<0.05$). The mean generation time (T_o) was the highest on yoghurt with 84. The mean generation time was statistically significant ($p<0.05$) (Table 4).

Total reproduction ratio (GRR) was highest on yoghurt (25.75) and corn flour (14.77). The GRR value for the other foods is zero since *H. illucens* fed domestically do not lay any egg. When reproduction limit (λ) was examined, the highest value was detected on banana and yoghurt, whereas the λ value was "0" because *H. illucens* females developed on tomato did not lay any eggs. The viability and reproduction rate curves of *H. illucens* fed on different food types are given in Figure 1.

In the group fed on yoghurt, the viability rate (lx) is constant until the 22nd day, then falls afterwards, and all adult females are completely dead on the 84th day. The rate of reproduction (mx) was highest compared to other foods. In the group fed on corn flour, the "lx" value was steady until day 12, then decreased, and all adult females died on day 52. The reproduction rate (mx) in corn flour was the second highest among other foods (Figure 1). In the group fed on bananas, the "lx" value was steady until day 16, then decreased, and all females died on day 48. The reproduction rate (mx) was the third among other foods (Figure 1). In the group fed on apple, the "lx" value was steadily decreased until the 15th day and then all adult females died on the 56th day. The reproduction rate (mx) on apple was found the least among other foods (Figure 1). In the group fed on tomato, the value of "lx" was fixed until the 11th day, then decreased, and all adult females died on the 56th day. The "mx" value could not be calculated because they did not leave eggs.

4. Discussion and Conclusion

As a result of feeding of *Hermetia illucens'* larvae on different food groups in the study, the longest developmental stages was with those who were fed yoghurt with 77.665 days. However, the total death rate of those who were fed with yoghurt was 90.2%. Laying eggs and hatching rates are also the second highest. The adult females of the group fed with yoghurt laid seven eggs packs. As a result, it has come to the conclusion that yoghurt is the right choice for the continuous production of *H. illucens.*

The development period was the second longest with 51.22 days until the group fed with tomatoes became

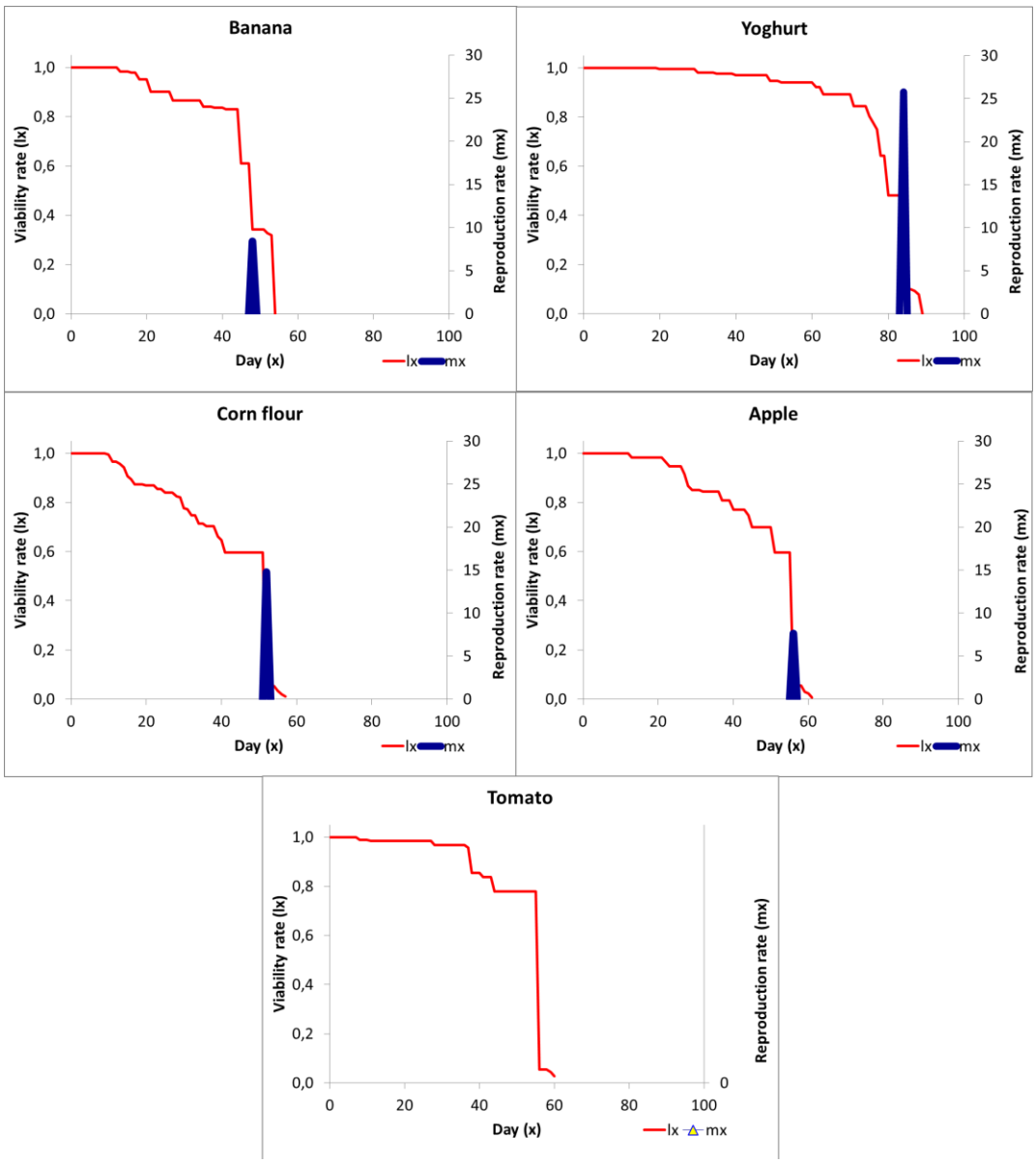

Figure 1. The viability and reproduction rate curves of *H. illucens* developed on different food types

mature and the total mortality rate of the development period was the second highest with 94.6%. Larvae have never laid any eggs in spite of their liked of tomatoes. It was reported on larval development of *H. illucens* fed with pork liver and fruit-vegetable mixture that the larval development period lasted 21 days on average in the pork liver [18], in the fruit-vegetable mixture [19]. It can be argued that these results are different from our work because of the fact that their larvae feed on different foods.

Although the development period till maturity was the third highest for apple-fed group with 48.55 days, the total death rate was the highest with 94.6% in the immature period. However, it has the lowest sexual rate and the third highest egg-laying rate.The adult females of the group fed on apples left only one egg package. Therefore, apple alone may not be the right choice to feed larvae. However, apples may be mixed suitable other foods. An average of 15 days of pupal development of *H. illucens* was reported on chicken feed at 28°C and 60% RH [18]. When these results are taken into consideration, it is seen that the food variety has an effect on the development of pupae When we look at the development period of *H. illucens* from egg to adult stage, it was determined that the highest period was observed on yoghurt with 77.66 days and the shortest one was observed on corn flour with 42.183 days. Regarding food types, significant differences were observed on the development of *H. illucens* from egg to adult stages.

The developmental period of immature stages on banana lasted 43.01 days till maturity, while the highest mortality rate was 65.8%. The development period of the group fed with bananas was 43.01 days, and the highest mortality rate was 65.8% in the longest.

The adult females which developed on banana left eight eggs packages. As a result, It has been come to the conclusion that banana is the right choice for continuous production of *H. illucens*. However, the

high market value of the banana in Turkey does not make it suitable for insect rearing, so we are convinced that it can be preferred in the African countries, which has a cheap banana production.

The period of development is maximum with 42.18 days until the group fed with corn flour is mature. The total mortality rate in pre-adolescence periods is highest with 94.8%. However, when it comes to sexual proportions, it is in the third highest position and fourth highest for laying the eggs number and hatching rates. The females developed on corn flour left only an egg package. As a result, corn flour can be used as a mix with other foods to rearing larvae, but it has been concluded that using corn flour alone is not the right choice. It was explained that the mortality rates of *H. illucens* larvae fed on chicken and meat at 25 °Cand 60% relative humidity were 80% in chicken feed and 60% in meat [20]. Also, the mortality rate of larvae of *H. illucens* at 28 °C and 70% RH was 55% in cucumber-fed and 50% in cucumber-fed kidney bean and sorghum-fed larvae was reported [21]. When these results are taken into consideration, the difference in the mortality rates can be attributed to food types.

In this study only five nutrients have been tested. *H. illucens* larvae preferred the fruit first, while the animal products were secondly preferred. Due to the fact that H. illucens females lay their eggs in a pack, they can not evaluate the outcome of only one package. We think that it would be more accurate to calculate the number of eggs left, egg hatching rates and sexual rates in the studies to be done for this. Similar studies to be conducted in the future will reveal which foods are preferred by the larvae of *H. illucens*. As a result of the work to be done, it must be determined that the use of waste organic materials in the production of this insect is more efficient. As a result, we are convinced that the importance of this insect, which contributes to the recycling of environment and waste materials, and the establishment of large building for production all over the world, is also understood in our country and we believe that the establishment of large insect production facilities will be encouraged.

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