EXPLORING THE CAPABILITY OF *Hermetia illucens* (Linnaeus, 1758) (*Diptera: Stratiomyidae*) TO RECYCLE ORGANIC WASTE IN ALGERIA

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Abstract

This study is being conducted to find out how to treat waste food by *Hermetia illucens* (L.). The impact of several diets on the life cycleand size of different development stages of this species was studied. *H. illucens* lays its eggs in heaps in nesting boxes, with an egg incubation period of 03 ± 0.9 days and a larval phase of 24.21 ± 4.10 days.The prepupa stage lasts approximately 03 days, and the transformation of larvae into pupae begins on the 16th day and lasts until the 41st day after the egg incubation. The sex ratio is 49,34 ±7.62% for females and 50.41± 7.74% for males.H. illucens larvae have an average weight of 0.13 ± 0.03 g, a length of 1.66 ± 0.14 cm, and a width of 0.46 ± 0.05 cm. Pre-pupa weigh 0.17 ± 0.06 g, pupa measures 02.05 ± 0.13 cm in length and 0.52± 0.04 cm in width, and adult weighs 0.03 ± 0.01 g. A hundred eggs weigh 0.0085 g, and the shell of the egg represents 63.42% of the egg.The black soldier fly larva consumes 0.36 to 0.47 g of food during its development, with an average value of food utilization of 75.57 ± 8.53%. At the end of the larval phase, the larvae reached a maximum size of 1.8 cm. The lipids and proteins contained in cheese and quail eggs improved the weight of larvae, resulting in a gain of 0.04 g/larva.*H. illucens* was bred on mud from a wastewater treatment unit with an average weight of 0.25 g, length of 2.12 cm, and width of 0.58 cm. The findings of this study indicate that food waste in Algeria can be utilized by black soldier fly larvae, resulting in a shorter development period and increased larval biomass.

Key words: Black solidier fly *Hermetia illucens*, waste management, Rearing method**.**

EXPLORER LA CAPACITÉ D'*Hermetia illucens* (Linnaeus, 1758) (Diptera : Stratiomyidae) À RECYCLER LES DÉCHETS ORGANIQUES EN ALGÉRIE

Cette étude vise à découvrir comment traiter les déchets alimentaires par *Hermetia illucens* (L.). L'impact de plusieurs régimes alimentaires sur le cycle de vie et la taille des différents stades de développement de cette espèce a été étudié. *H. illucens* pond ses œufs en tas dans des nichoirs, avec une période d'incubation des œufs de 03 ± 0,9 jours et une phase larvaire de 24,21 ± 4,10 jours. Le stade pré-pupe dure environ 03 jours et la transformation des larves en pupes commence le 16ème jour et dure jusqu'au 41ème jour après l'incubation des œufs. Le sex-ratio est de 49,34 ± 7,62 % pour les femelles et de 50,41 ± 7,74 % pour les mâles. Les larves de *H. illucens* ont un poids moyen de 0,13 ± 0,03 g, une longueur de 1,66 ± 0,14 cm et une largeur de 0,46 ± 0,05 cm. . La pré-pupe pèse 0,17 ± 0,06 g, la pupe mesure 02,05 ± 0,13 cm de longueur et 0,52 ± 0,04 cm de largeur, et l'adulte pèse 0,03 ± 0,01 g. Une centaine d'œufs pèsent 0,0085 g, et la coquille de l'œuf représente 63,42 % de l'œuf. La larve de la mouche soldat noire consomme 0,36 à 0,47 g de nourriture au cours de son développement, avec une valeur moyenne d'utilisation alimentaire de 75,57 ± 8,53 %. A la fin de la phase larvaire, les larves atteignent une taille maximale de 1,8 cm. Les lipides et protéines contenus dans le fromage et les œufs de caille

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ont amélioré le poids des larves, entraînant un gain de 0,04 g/larve de *H. illucens* a été élevé sur de la boue provenant d'une unité de traitement des eaux usées avec un poids moyen de 0,25 g, une longueur de 2,12 cm et une largeur de 0,58 cm. Les résultats de cette étude indiquent que les déchets alimentaires en Algérie peuvent être utilisés par les larves de mouches soldats noires, ce qui entraîne une période de développement plus courte et une augmentation de la biomasse larvaire.

Mots clés : Mouche soldat noire *Hermetia illucens,* gestion des déchets, Méthode d'élevage.

Introduction

In Algeria, an estimated 13.5 million tons of household waste is generated each year, of which 53.61% is organic waste (AND, 2020), not counting the amount of waste produced by the agricultural sector has not yet been determined. Currently, most of the organic waste is sent to landfills or technical landfill centers, which can lead to environmental pollution. However, there are several methods available to treat and recover this waste, such as converting it into bio-fertilizers or animal feed. Insect rearing has proven to be an effective method in several countries. This involves raising insects on organic waste, which they consume and transform into biomass that can be used as animal feed. The remaining livestock residues can be used as compost to fertilize crops. The black soldier fly (BSF) (*Hermetiaillucens*) is a well-known arthropod for processing organic waste. It belongs to the family Stratiomyidae (Insecta: Diptera) and the subfamily Hermetiinae. The antennae of individuals in the Hermetia group are laterally flattened, with the 8th flagellomer being thick and elongated (Woodley, 2001). Adults resemble wasps and can be quite large. While some species in the genus Hermetia are considered pests, such as *Hermetiapalmivora* which attacks oil palm (James, 1972a), *H. illucens* feeds only on decomposing organic matter of all kinds, including leftovers from meals, vegetables, fruits, and manure. BSF is of interest due to its ability to recover more than 70% of its diet in biomass (Tomberlin, andSheppard, 2010), and its larvae provide important nutrients like proteins, lipids, and minerals for animals.In addition, the production of black soldier fly larvae has been shown to have environmental benefits, such as reducing greenhouse gas emissions and minimizing the use of land and water resources (Oonincx et al., 2010).This process not only generates an added value for farmers producing dates, but it also reduce waste and provides a sustainable solution for animal feed production.Additionally, the larvae's quick decomposition and the resulting compost has high potential as a sustainable alternative to traditional composting methods, offering benefits such as suppressing soil-borne plant pathogens, controlling weeds biologically, and improving plant nutrient availability (Widyastuti et al, 2021).Black soldier fly larvae are high in protein, fat, and minerals, making them a nutritious feed ingredient for livestock such as chickens and fish (Barragan-Fonseca et al., 2020). The larvae can consume large amounts of organic waste material, including low-quality dates, and convert them into biomass suitable for animal feed (Diener et al., 2011).Furthermore, using black soldier fly larvae as a feed ingredient has environmental benefits, as it reduces the dependence on traditional protein sources such as soybean and fishmeal, which are often associated with deforestation and overfishing (Makkar et al., 2014). Additionally, insect meal has a lower environmental impact compared to conventional protein sources and can be sustainably produced using organic waste streams (Van Huiset al. 2016).

The aim of our work is to study the potential of the BSF in the recovery of organic waste in Algeria.

Material and methods

Insect origin

BSF larvae samples were acquired from a farmer in the El Oued region (Southeastern Algeria) in order to start a rearing unit in our laboratory located in the Sidi Mehdi experimental station of the National Institute of Agronomic Research of Algeria (INRAA). The larvae were then placed in plastic boxesmeasuring 15(L) x 10(W) x 10(H) cm and kept in an environmental room at 24.42 ± 3.4°C, 60 ± 10% relative humidity (RH), and 16:8 L:D until the emergence of adults.This created an ongoing culture that has been upheld for three years.

Experiment trials

The fly's eggs are placed on a tulle at a height of about 10 cm from the food substrate and presented to the insects in basins 35 cm in diameter, in order to avoid any contact of the eggs with the water which can make them explode. After hatching, the larvae gain the food and start feeding until they reach the end of the larval phase. They then turn into pre-pupae, at this stage their color becomes black (May, 1961), they stop feeding and leave the food substrate in search of a dry, dark place to pupate. The pupae are recovered and placed in basins about 15 cm in diameter containing compost and then kept in black cages (pupation cages) with 40x80x50 cm size until the emergence of the adults. Thesecages are connected to the mating cages with 50x60x100 cm which are covered of a tulle which prevents the flies from escaping and allows ventilation and the penetration of light. Nest boxes, made up of five 15 cm pieces of wood tied together, and a drinker in the form of a 15x10x10 cm plastic box containing a sponge soaked in water, are placed inside the mating cages. Adults were not given nourishment because is not necessary for effective reproduction (Sheppard et al, 2002). The females insert their eggs between the pieces of wood placed inside these enclosures. The eggs are harvested every day using a knife. The first 05 days after hatching, larvae are fed with broiler feed obtained from the market. Afterwards, varied organic dietswere presented to the insects. Rearing was carried out at a temperature of 24.42 ± 3.43° C., a humidity of 60 ± 10% and a photoperiod of 16 h of light and 8 h of darkness.Biological parameters of *H. illucens* were noted from the rearing unit. Morphological parameters were obtained by measuring the weight, the length, and the width of the larvae, prepupae, pupae, and adults.An analytical balance was used to measure weight, and millimeter paper was used to measure length and width.

To determine the larval development rate and biomass, weight samples of the larvae were taken every day. Starting with 5-day-old larvae, larvae were weighed using an analytical balance. To study the fecundity of H. illucens, adult couples were each placed in boxes covered with mosquito netting; the eggs laid were noted until the death of the flies. Longevity of females and females was also noted. The growth rate of black soldier fly larvae fed different diets was investigate by checking the development of thirty larvae of the same age rearing onfive diets (The remains of bread, The remains of bread plus cheese, The remains of bread plus quail eggs, The remains of bread plus milk powder and residual mud from a wastewater treatment unit). The development rate of the BSF larvae reared on the remains of bread and dates waste has also examined.

Statistical analyzes

The statistical analyzes of this study were carried out using both Excel, R and SPSS software.

Results

The eggs of *H. illucens* females are laid in piles within the spaces intentionally left between the pieces of wood in the nesting boxes. The incubation period for the eggs is 03 ± 0.9 days, while the larval phase lasts 24.21 ± 4.10 days(table 01). The prepupal stage typically lasts around 03 days, during which pre-pupae cease feeding and depart the food substrate to locate a dry and shady area for the pupal phase to occur. The transformation from larvae to pupae begins on the 16th day after hatching and may take up to the 41st day (Fig.01). By the 26th day, over 51% of the larvae have already converted into pre-pupae, and by the 32nd day, a transformation rate of 81% is achieved. Males usually emerge before females, with a sex ratio of 49.34 ± 7.62% for females and 50.41 ± 7.74% for males. A study on the fecundity of *H. illucens* reported an average weight of 0.018 ± 0.003 g of eggs per female which constitute an average of 215.6 ± 36.18 eggs per female.The phenomenon of parthenogenesis was not observed in our experiment.On average, a hundred eggs weigh approximately 0.0085 grams, and the eggshell makes up about 63.8 ± 7.42% of the egg. At six days old, the larvae weigh an average of 0.029 ± 0.01 grams per individual. Once fully developed, the larvae can weigh up to 0.13 ± 0.03 grams per larva, measuring 1.66 ± 0.14 cm in length and 0.46 ± 0.05 cm in width (Tab. 02). Pre-pupae weigh an average of 0.17 ± 0.06 grams per individual, measuring 2.15 ± 0.16 cm in length and 0.5 ± 0.00 cm in width. Pupae are about 02.05 ± 0.13 cm in length and 0.52 ± 0.04 cm in width, weighing 0.19 ± 0.03 grams per individual. The weight of adult insects (both genders combined) is 0.03 ± 0.01 grams per individual, with a length of 1.47 ± 0.31 cm and a wingspan width of 2.38 ± 0.26 cm. Adults can live for about 12 days, and no significant difference has been observed between the two sexes. During their development period, the black soldier fly larvae consumed approximately 0.47 ± 0.36 g of food.

Table 1. - Biological parameters of *Hermetiaillucens* at an average temperature of 24.42 ± 3.43°C, humidity of 60 ± 10% and a photoperiod of 16 h light and 8 h dark.

Development time (Day)				**Adult Longevity (Day)**		**Sex ratio (%)**	
Egg incubation	**Larval stage**	**Pre-pupal stage**	**Pupalphase**	**Male**	**Female**	**Male**	**Female**
03±0.9 (N=20)	24.21 ± 4.10 (N=14)	17.63±9.30	10.44 ± 1.67 (N = 35)	12.24 ± 2.34 (N = 88)	12.10 ± 1.77 (N = 73)	50.41 ± 7.74 (N=35)	49.34 ± 7.62 (N=35)

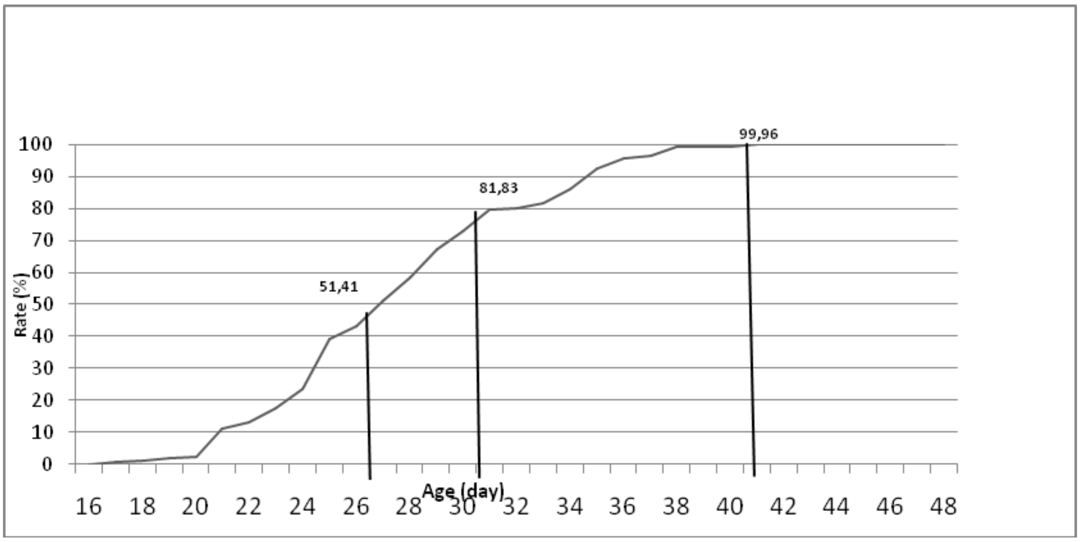

Figure 1. - Rate transformation of BSF larvae into pre-pupae stage.

Table 2. - Morphological characteristics of *Hermetia illucens* during various developmental stages

Developmental stage	**Weight (g)**	**Length (cm)**	**Width (cm)**
Egg (100 eggs)	0.0085 ± 0.00 (N = 6)	/	/
Larva (last stage)	0.13 ± 0.03 (N=51)	1.66 ± 0.14 (N=51)	0.46 ± 0.05 (N=51)
Prepupa	0.17 ± 0.06 (N=107)	2.15 ± 0.16 (N = 30)	0.5 ± 0.00 (N = 30)
Pupa	0.19 ± 0.03 (N=51)	2.05 ± 0.13 (N=51)	0.52 ± 0.04 (N=51)
Adult (Male and female)	0.03 ± 0.01 (N=25)	1.47 ± 0.31 (N=25)	2.38 ± 0.26 (N=25)

There was no significant difference observed in the growth rate of black soldier fly larvae fed dates and bread (Fig. 2), and both diets resulted in larvae reaching a maximum size of 1.8 cm at the end of the larval phase. The study found that after 16 days, the larvae reached the same size, which is useful information if they are being used as food because keeping them longer would be wasteful. In terms of food valorization rate, *H. illucens* larvae were able to transform 77.27 ± 1.74% of dates and 74.11 ± 0.65% of bread.

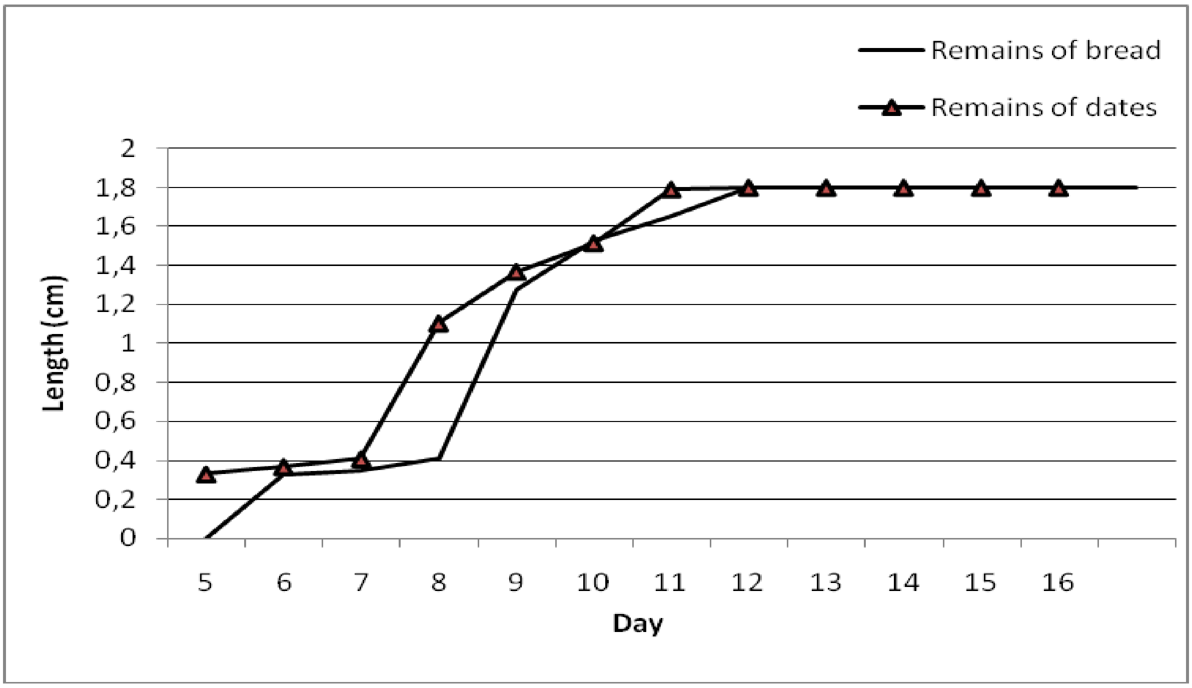

Figure 2. - Growth rate (Cm) of *Hermetia illucens* larvae reared on meal scraps and date scraps

The average weights of the larvae obtained on different diets (Bread, Breadplus cheese, Breadplus quail eggs, Breadplus milk powder and residual mud) are 0.33 ± 0.03 g, 0.37 ± 0.03 g, 0.37 ± 0.03 g, 0.33 ± 0.03 g and 0.25 ± 0.05 g for the fivesubstrates respectively (Tab. 03). The statistical study reveals highly significant differences because the p-value is less than (Tab. 04), which means that the mean weight of the black soldier fly larvae differs across at least two diets. We can also look at the F-statistic and see that it is quite large (F = 22,03), indicating a strong effect of the diets on the weight of the larvae.From the Tukey HSD test, we can determine which diets are significantly different from each other, we can see that there is a significant difference between the mean weights of the larvae fed with bread plus cheese and those fed with bread ($p < 0.05$), as well as between the mean weights of the larvae fed with bread plus cheese and those fed with mud ($p < 0.05$). There is also a significant difference between the mean weights of the larvae fed with bread and those fed with mud ($p < 0.05$). The mean weights of the larvae fed with bread plus milk and bread plus eggs do not differ significantly from those of the other diets ($p > 0.05$). There is high difference in in favor of food substrates containing cheese (p = 0.00027, DDL = 29) and quail eggs (p = 0.00012, DDL = 29) and not significant for milk (p=0.786, DDL=29). A breeding of H. illucens on the mud from the wastewater treatment unit in the Touggourt region was conducted. A quantity of 05 kg of mud was placed in basins of 45 cm in diameter for each. Regarding the production of BSF larvae on residual mud from the wastewater treatment unit The larval phase lasted 03 weeks, and a production of 02 kg of fresh larvae was obtained. The average weight of the larvae was 0.25 ± 0.05 g, the length was 02.12 ± 0.24 cm and the width 0.58 ± cm (Table 3)

Table 3. - Weight of *Hermetiaillucens* larvae reared on different food substrates

Diet	**Weight of larvae (g)**
Bread	0.33 ± 0.03 (N = 30)
Bread plus cheese	0.37 ± 0.03 (N = 30)
Bread plus eggs	0.37 ± 0.03 (N = 30)
Bread plus milk	0.33 ± 0.04 (N = 30)
Residualmud	0.25 ± 0.05 (N = 30)

Table 4. - Anova table of different diets used to rear BSF larvae

Source of Variation	**SS**	**df**	**MS**	**F**	**p-value**
Between Groups	0.00217	4	0.00054	22.03	1.07e-12
Within Groups	0.00298	84	0.00004		
Total	0.00515	88			

Discussions

The present study demonstrated that the black soldier fly (Hermetiaillucens) larvae are capable of normal development on various food sources. The life cycle of this insect is comprised of several distinct phases, with the larval phase lasting 24.21 ± 4.10 days. The findings of this study are consistent with previous research by Tomberlin et al. (2002) and Cammack and Tomberlin (2017), which reported a similar duration for the larval phase. In contrast, the results of Miranda et al. (2019) and Ewusie et al. (2019) reported shorter durations for the larval phase. These differences in development time can be attributed to variations in diet quality and environmental factors, which have been shown to impact larval development. In particular, larvae fed a high-protein diet developed more quickly, had higher survival rates, and lived longer than those fed a low-protein diet, as reported by Cammack and Tomberlin (2017).

In terms of adult longevity, our results are higher (12 days) than those reported by other researchers. Tomberlin et al. (2002) found that adults provided with water lived longer (7.9 to 9.7 days) than those without (6.1 to 7.1 days). Miranda et al. (2019) reported lower longevities of 4.9 to 8.1 days for males and 4.7 to 6.7 days for females, while Cammack and Tomberlin (2017) recorded longevity of 4.6 to 6.9 days. Moreover, adult males usually emerge before females, which is consistent with findings by Mbenoun Masse et al. (2022).

The sex ratio of black soldier fly larvae shows an approximate 50% female population, which is lower than the results reported by Gobbi et al. (2013),Liu et al.(2008)and Tomberlin et al. (2002). The fecundity of females belonging to the species *Hermetiaillucens* is around 215.6 ± 36.18 eggs per female (Tomberlin et al., 2015).No parthenogenesisreproduction of black soldier flies female was recorded in our study. This finding is the same recorded byTomberlin et al. (2002).

In our study, the BSF larvae attained a weight of 0.13 ± 0.03 g and a length of 1.66 ± 0.14 cm. However, these values are comparatively lower than the range of weights (0.15 to 0.17 g) reported by Tomberlin et al. in 2002. The weight and size of *H. illucens* larvae are influenced by the type of diet provided to them. Similarly, Mbenoun Masse et al. have also reported different values for the weight and size of *H. illucens* larvae, highlighting the effect of diet on the growth of these organisms.The larvae are rich in protein and contain essential amino acids, making them a suitable substitute for traditional protein sources such as fishmeal and soybean meal (van Huis et al., 2013).

In terms of morphological parameters, the diet presented to larvae has a significant impact on their weight and size. Nonetheless, the weight of larvae observed in our study (0.13 ± 0.03 g) is lower than that recorded by Tomberlin et al. (2002) (0.15 to 0.17 g), Mbenoun Masse et al. (2022) (0.18 ± 0.03 g), and Fitriana et al. (2021) (0.38 ± 0.05 g). Similarly, the length of larvae is also lower (1.66 ± 0.14 cm) than that observed by Mbenoun Masse et al. (2022) (2.02 cm).This situation canattributed to the diet quality.

The average weight of black soldier flypre-pupae is 0.17 ± 0.06 grams per individual. However, the weight of pre- pupae can vary from 0.12 g to 0.22 g depending on the food provided to the larvae, as reported by previous studies (Tomberlin et al, 2002; Miranda et al, 2019). Several studies have reported similar findings regarding the weight of black soldier fly pre-pupae. In a study by Newton et al. (2015), the average weight of the pre-pupae was reported to be 0.18 ±
0.01 g, which is consistent with the value reported above. Similarly, in a study by Liu et al. (2021), the average weight of the pre-pupae was reported to be 0.16 ± 0.03 g, which is within the range of the reported average weight.

Larvae rose on energy-dense diets producing prepupae with high fat content and a concentration of medium chain fatty acids may have advantages over those fed on standard feed sources.This weight varies depending on various factors such as rearing conditions, feeding regimes, and genetic traits of the species. For instance, larvae fed on diets with high protein content have been shown to attain higher weights compared to those fed on low protein diets. Similarly, rearing temperatures, humidity, and the size of the rearing containers also affect the weight of the pre-pupae.The average weight of the pre-pupae is important as it affects their subsequent development into pupae and adult flies, which in turn determine the overall production output of the black soldier flies. In addition, the weight of the pre-pupae is also important in assessing the nutritional value of the insects as a potential feed source for livestock (Li et al., 2012).

The average weight of adults (combining both genders) was 0.03 ± 0.01 grams per individual in our study. Several studies have reported similar findings regarding the weight of black soldier fly adults. Other researchers have recorded a weight ranging from 0.085 g to 0.111 g (Tomberlin et al, 2002; Georgescu et *al.*, 2020; Miranda et al, 2019; Oonincx et *al.*, 2015).Similarly, in a study by Wang et *al.* (2019), the average weight of adult black soldier flies was reported to be 0.029 ± 0.005 g, which is within the range of the reported average weight.Nonetheless, males are consistently smaller than females, as reported by Oliveira et al (2015). Additionally, wild-caught individuals are larger and have longer life spans than their farmed counterparts, according to Tomberlin et al (2002).The average weight of black soldier fly adults is an important parameter that affects their overall reproductive success and potential use as a protein source. The weight of the adults also affects their flight capability, which is crucial for mating and dispersal, and it is also important in understanding their ecological role and impact on the environment.

Dates of low market value can be valued by the production of the larvae of the black soldier fly intended for the food of the farm animals (chicken and fish) which constitutes an added value for farmers producing dates. In fact, there was no significant difference observed in the growth rate of black soldier fly larvae fed dates and bread, and both diets resulted in larvae reaching a maximum size of 1.8 cm at the end of the larval phase.

In reference to larval food intake, the outcomes derived from our investigation reveal a greater proportion of consumption, specifically 77.27 ± 1.74% and 74.11 ± 0.65% for dates and bread, respectively. These results are superior to those observed in prior research by Fitriana et al (2021), wherein rates of 54.5 ± 16.8%, 45.8 ± 12.0%, and 46.3 ± 10.8% were recovered from residual meals, livestock feed, and fecal matter, respectively.In the course of their growth phase, the larvae of the BSF were found to have ingested roughly 0.47 ± 0.36 g of food. This aligns with the work of Cammack and Tomberlin (2017), who postulate an average daily intake of 0.04 g per larva.

Diener et *al.* (2011) investigated the feeding preferences of black soldier fly larvae by offering them different types of food, including fruits, vegetables, grains, and meat. The results showed that the larvae consumed a greater proportion of fruits, particularly bananas and dates, compared to other food types.Another study by Khusro et al. (2019) examined the growth and development of black soldier fly larvae fed on different types of food, including bread. The authors found that bread could be a suitable feedstock for black soldier fly larvae and resulted in good growth rates. These finding are confirmed by the results of our study.

The present investigation has demonstrated the feasibility of utilizing food waste in Algeria as a substrate for the rearing of BSF larvae, leading to a shortened development period and a higher final larval biomass. Such benefits can potentially reduce rearing costs while generating a greater yield of valuable products, namely protein- and fat-rich larvae.

These results show that the lipids contained in the cheese and the proteins contained in the eggs made it possible to improve the weight of the larvae. A gain of 0.04 g/larva is obtained.

Although encouraging results have been obtained by breeding black soldier flies on residual mud, further research is warranted, particularly with regard to evaluating the presence of pathogens and heavy metals in the reared larvae. In addition, future studies should also examine the nutritional composition of BSF larvae reared on different food residues, in order to enable more precise interpretations.

Further research is also necessary to determine the optimal inclusion level of insect meal in poultry feed for different species and production stages. Manipulating the protein and carbohydrate content of the diet by adding certain waste food products such as eggs, milk, cheese, has been found to optimize the growth and development of BSF larvae. This information may facilitate the development of more efficient and effective methods for utilizing black soldier flies in waste management and other applications, such as animal feed production.

Overall, the utilization of low-value dates for BSF production is a promising solution for the sustainable production of animal feed, while also providing added value for farmers.Also, the use of BSF to treat waste food can be employed to reduce the volume of solid food waste and can be integrated into waste management systems in Algeria.

Conclusion

This approach contributes to reducing food waste, improving animal nutrition, and promoting sustainable agriculture.The findings of this study indicate that food waste in Algeria can be utilized by BSF larvae, resulting in a shorter development period and increased larval biomass. This approach can lead to reduced rearing expenses and a higher yield of valuable products, such as protein- and fat-rich larvae. Additionally, the study suggests that low-value dates can be transformed into a valuable resource for farmers by producing black soldier fly larvae as feed for farm animals like chickens and fish. Expired food products can added to the BSF diet to improve the quality of the larvae produced. While the use of residual mud for breeding black soldier flies has yielded promising results, further investigation is necessary to assess potential risks associated with pathogens and heavy metals in the larvae. Future research should also focus on analyzing the nutritional composition of black soldier fly larvae reared on various food residues to obtain more precise insights.

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