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Production of *Hermetia illucens* L and *Musca domestica* L larvae (maggots) for animal feed in West Africa: A review

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ABSTRACT: In the search for new, cheaper and environmentally sustainable sources of protein-rich food, much research has shown the alternative role that insects could play in animal feed. Fly larvae or maggots have been identified as a food source that is very rich in protein, dietary fat, vitamins and minerals. The most commonly used maggots in animal feed are those of the housefly (*Musca domestica* L. 1758) and the black soldier fly (*Hermetia illucens* L. 1758). Different maggot production systems for these two fly species have been developed and others are still being developed in different contexts around the world. The production of these maggots does not require much expenditure as they can be easily obtained from animal and/or plant waste available free of charge or at low cost. This study summarizes the available literature on the methods of production of maggots of these two fly species and their use in animal feed. Also, the zootechnical performance of animals fed with maggots and the importance of maggots were discussed in this study.

KEYWORDS: Maggots, proteins, animal feed, zootechnical performance, fly.

1 INTRODUCTION

The rapid growth of the world's population and the need for a better standard of living in many countries have led to a sharp increase in the demand for meat, eggs and fish [1] This trend has important environmental implications, especially to feed production, as in the absence of equivalent animal production, this increase will lead to protein shortages [2].The FAO estimates that food production will have to increase by 70% to feed the world in 2050, with meat production (beef, poultry and pork) expected to double [3]. Therefore, the impact on the demand for livestock feed becomes enormous in economic terms [4]. One of the main problems of livestock production is the cost of feed, especially conventional protein sources such as fishmeal and soybeans, which account for 60-70% of feed expenditure [5]. Hence, the misuse of fishmeal and soybean in animal feed leads to overfishing and the exploitation of large areas of land, respectively, as well as intensive soybean monocultures that cause soil depletion and deforestation, thus contributing to climate variability and change [6]. In addition, fishmeal and soybean are imported at very high costs in most sub-Saharan African countries. In order to solve it, alternative sources of protein that are economically and ecologically viable should be identified. At the global level, insect farming may be a solution to the inaccessibility of conventional protein sources and to food insecurity. Indeed, the nutritional composition of insects is comparable to that of conventional plant and animal protein sources [5], [7]. In general, the crude protein content of insects varies between 13% and 77% on a dry weight basis and is dependent on the species, its stage of development but also the substrate on which it was fed [8]. Their lipid content also offers good prospects for incorporation as a feed supplement in animal feed [9], [10]. In Africa, numerous studies have shown that insects can be incorporated into the diet of farm animals such as poultry, fish and pigs [5], [7], [11], [12]. The authors [13] reviewed insects as a substitute in animal nutrition and found that some Diptera, Coleoptera and Orthoptera had a better fatty acid content compared to fish meal. In Burkina Faso and Benin the incorporation of insects in the diet of animals has been investigated by some authors [14], [15], [16]. Insects of the order Diptera used in the diet of farm animals are flies such as the housefly (*Musca domestica,* Muscidae), the black soldier fly (*Hermetia illucens,* Stratiomyidae) and the Caliphoridae [14]. In recent years, a lot of research has been conducted on mass production of larvae and rearing of flies for the purpose of feeding farm animals. In Burkina Faso, [17] and [18] have conducted studies on housefly maggots, mainly on the methods of mass production of these maggots and their acceptability by local guinea fowl and chickens. In this study, we will focus mainly on the use of insects, especially the maggots of houseflies and black soldiers in animal feed. The use of these larvae to supplement traditional animal feed sources such as soybeans, maize, other cereals and fishmeal would allow farmers to reduce their production costs.

2 Methodology

This summary document is based entirely on the available scientific data on the use of maggots in animal feed. Available literature on maggot production methods, maggot extraction and drying methods, use of maggots in animal feed as well as zootechnical performance of maggot-fed animals published in peer-reviewed journals with a wider scope for researchers, articles, books, periodicals, abstracts, research reports, conference papers and other technical reports has been compiled. Online database tools such as Research Gate, Google scholar, Web of Science and Scopus were used for literature searches. This article is the result of one hundred (100) research publications, of which more than twenty-five (25) are from West Africa. The key search words were: fly larvae, maggots, houseflies, *Musca domestica,* Housefly larvae production, black soldier flies, *Hermetia illucens,* black soldier fly larvae production, animal feed, importance of fly larvae, substrates, containers, attractants.

3 Main Insect Species Used In Animal Feed

The insects used in animal feed include Diptera, Coleoptera, Termites, Grasshoppers and Lepidoptera. Diptera is the order of insects with the largest number of species that can be used in animal feed. Within this order, flies are the most abundant [19]. Among these flies, the ones most used in animal feed are mainly the black soldier fly (*Hermetia illucens* Linnaeus, 1758), the housefly (*Musca domestica* Linnaeus, 1758) and several Calliphoridae species [14]. The larvae of many Coleoptera are used in animal feed [4]. For example, the miller beetle or mealworm (*Tenebrio molitor* L., 1758) offers an interesting alternative to soybean or fish meal [13]. There are also larvae of wood borers and dung beetles, *Alphitobius diaperinus, Zophobas morio* and larvae of palm weevils of the genus Rhynchophorus. Cerambycidae, Scarabaeidae and Curculionidae are also used as supplements in poultry and fish feed [4]. Isopterans (termites) are also used as animal feed in many parts of the world [4]. Indeed, it is not uncommon to see poultry feeding on termites in rural areas; making termites a natural food source for many birds [16], [20], [21]. In the wild, avian fauna and even roaming poultry consume locusts and grasshoppers, which belong to the order Orthoptera [22]. Some insects of the order Lepidoptera are also consumed by animals, such as silkworms (*Bombix moris*), which have been found to be cheaper than conventional fishmeal, making them an economically attractive substitute [23].

4 General Characteristics Of Flies

Diptera are one of the largest and most diverse orders of insects. These Diptera have one pair of wings (forewings), the second pair of wings (hindwings), is replaced by a pair of organs called dumbbells or pendulums [24]. They have a large and mobile head with compound eyes, often very large, and mouthparts of the sucking, piercing, sponge type (all adapted to liquid feeding). The number of described Diptera species in the world is 160,000, which represents about 10% of all known animal species. Experts estimate that there must be between 400,000 and 800,000 species of Diptera [24], making them the fourth most abundant order after Lepidoptera, Hymenoptera and Coleoptera. Many species belonging to the order Diptera are found in almost all regions of the world. These species are well adapted to a wide range of habitats and, with the exception of the deep ocean, can live in many habitats on land [25]. The housefly (**Photo 1a and 1b**) has aroused the interest of the scientific community and those specializing in animal feed [5], [7], [11], [26], [27]. Indeed, it has a high potential to convert organic matter into body biomass thanks to its larvae; this offers a credible alternative to conventional sources of nutrients for fish, pigs and poultry [5], [7], [12].

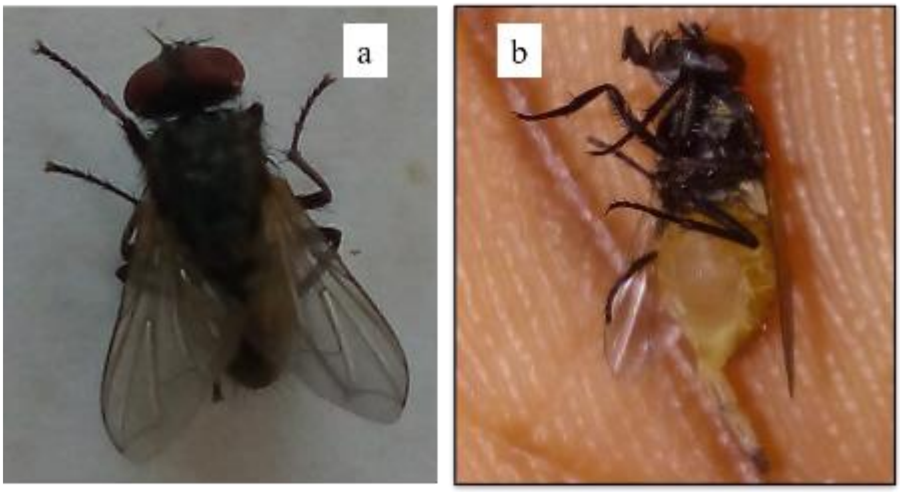


Photo 1: (a) = dorsal view of a housefly, (b) = female housefly; (Sankara, 2022)

Another fly species that has received particular attention from researchers is the black soldier fly (**Photo 2a, 2b and 2c**). Native to North America, the black soldier fly, which in its adult state resembles a black wasp, has acclimatized to all warm, tropical and subtropical climates of the world [28]. Its name comes from their tendency to position themselves in the same direction when moving in numbers. It is interesting because of the ability of its larvae to feed on decaying organic matter and its high content of useful macronutrients in the diet of some farm animals [10], [14], [29].

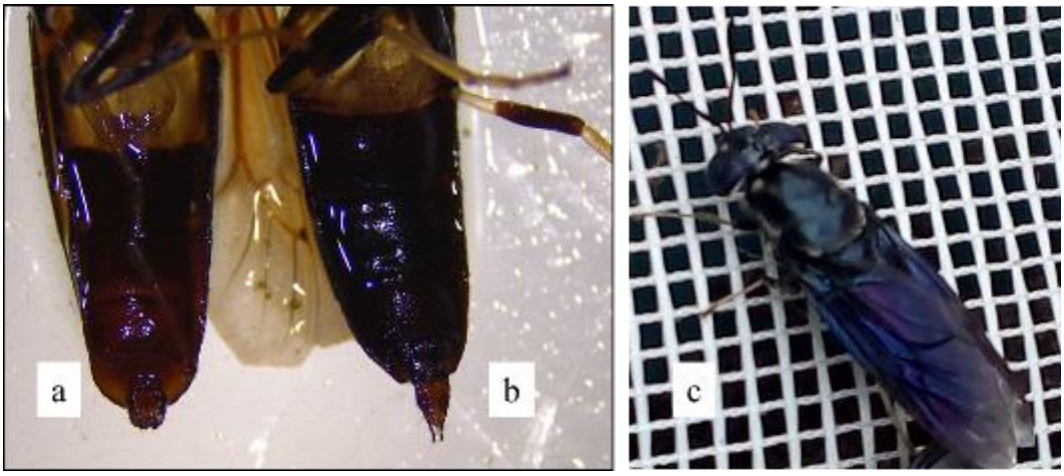


Photo 2: Male (a) and female (b) black soldier fly; dorsal view (c); (Sankara, 2022)

5 Life Cycle Of Flies

Flies undergo a complete metamorphosis and have four distinct stages of development: egg, larva or maggot, pupa or nymph and adult.

5.1 Life Cycle Of The Housefly (*Musca Domestica*)

Eggs: the female housefly lays its eggs one by one and piles them up in small heaps. It lays about 75 to 150 eggs at one time. It repeats the process until it has laid about 600-900 eggs in her lifetime. The eggs are laid in decaying organic matter [30]. They are elongated and oval in shape, measuring about 1-2 mm in length. Eggs are white and develop best in droppings with 40-70% humidity. Egg hatching time decreases with higher temperatures and varies between 8 and 24 hours [30]. Often, several flies lay their eggs in close proximity to each other, so there may be a large number of larvae and pupae in the same location. Female flies need access to suitable food to produce eggs [30].

Larva: it is composed of 12 segments. It is white and about 1-2 mm long when it hatches. A pair of spiracles is present at the anterior and posterior end of the body. The larva feeds on decaying plant or animal organic matter. It evolves in three stages and the duration of the stages decreases with increasing temperature (2-7 days) [31]. Stage 1 larvae prefer damp places and tend to be lucifugous. Stage 3 larvae will migrate to a drier, brighter environment. Larvae can survive for several days at 2°C. However, below 10°C, they should not pupate. In winter, the larvae are able to migrate to warmer areas to continue their development. Young larvae seek high temperatures (30-37°C), whereas an older larva will prefer lower temperatures to reach its pupation optimum. The maximum lethal temperature of the larva is not precisely known but is around 46°C and varies according to the development stage [31].

Pupa: the pupal envelope (puparium) is initially creamy white and quickly darkens to reddish brown and then almost black [31]. The pupal stage lasts 3-6 days, but in winter it can be prolonged. Pupation frequently takes place on the surface of rather dry droppings. At the end of the stage, the puparium ruptures in a circular fashion at its front end due to the efforts of the young fly. The increase in temperature causes a decrease in the duration of pupation. However, there are thresholds below 11°C and above 38°C where development is interrupted [31].

Adult: the housefly is 5-7 mm long, with the female usually larger than the male. The head has reddish eyes and spongy mouthparts. The thorax has four narrow black stripes and the fourth longitudinal rib of the wing is strongly curved upwards [31]. The abdomen is grey or yellowish with a dark midline and irregular dark markings on the sides. The underside of the male is yellowish. The sexes can be easily separated by identifying the space between the eyes, which in the female is almost twice as wide as in the male. The life span of houseflies varies from about 20 to 40 days [17]. The development cycle of the housefly is summarized as shown in **figure 1.**

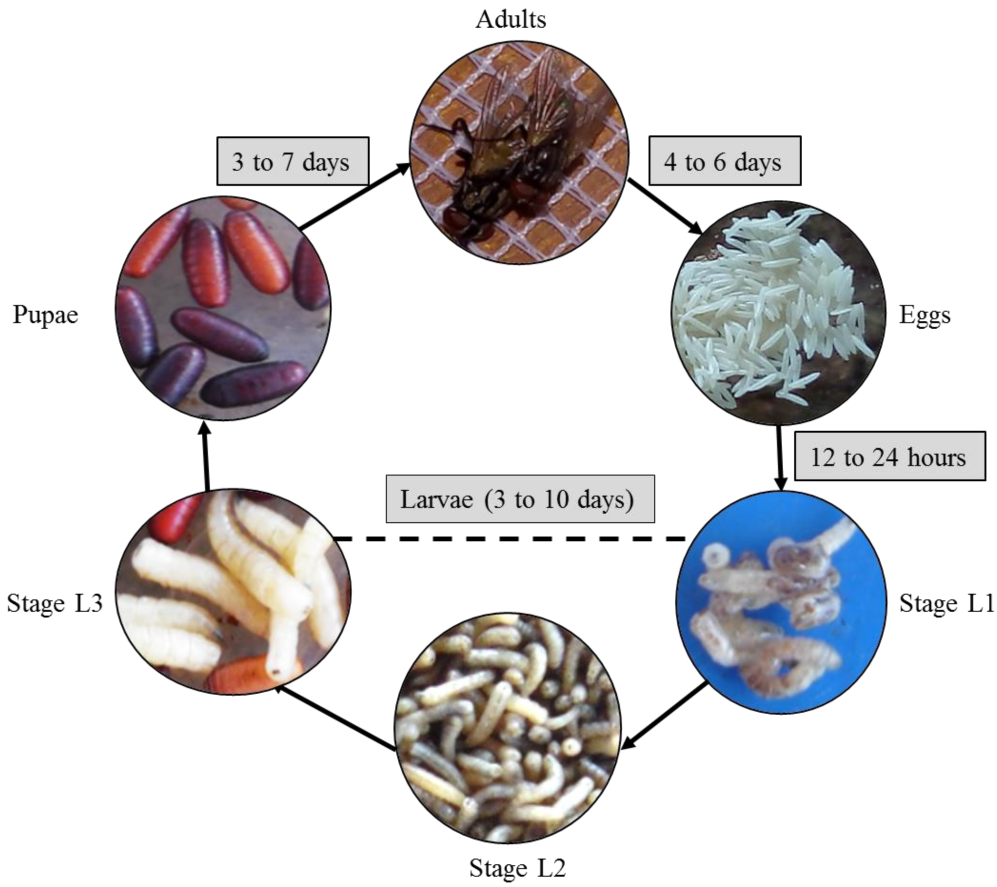


Fig. 1. Life cycle of the housefly (adapted from Sankara, 2017)

5.2 LIFE CYCLE OF THE BLACK SOLDIER FLY, *HERMETIA ILLUCENS*

Eggs: a few days after reaching adulthood and emerging from the pupae, female black soldier flies find a mate. This happens when a male intercepts a female in flight and the two descend in copulation [32]. The female wastes no time in laying more than 500 eggs in a dry environment, near the edges or crevices of decaying organic matter [32]. In this way, the eggs are protected from drying out and humidity as well as from predators [33], [34]. The eggs are egg-shaped and each egg is about 1 mm long and creamy white [32]. They change from beige to yellow/beige during the incubation period, which lasts 3 to 5 days at 27-30°C [35].

Larvae: As soon as the eggs hatch, the larvae are 0.66 mm long and use the surrounding organic matter as a food source. Temperature is a major parameter influencing larval development and survival rates, with the optimum temperature being between 20 and 30°C [33]. As they grow, the larvae undergo moults separating 5 larval stages that take place between 14 and 18 days. However, it can take up to 6 months for the larvae to reach maturity due to the ability of black soldier fly to extend their life cycle in hostile circumstances. The larvae can measure up to about 27 mm long and 6 mm wide. They are pale white with a small black head containing their mouthparts [36]. Morphologically, it is difficult to differentiate the first four larval stages (except for body size), but the 5th larval stage is characterized by a marked change to a beige color. The 6th instar is the prepupal stage which is characterized by a dark brown color and migration out of the substrate (facilitated by a modification of the mouth organs in the form of hooks) and then transforms into a pupa [37].

Pupae: pupae are 12 to 25 millimeters long and their rigid, calcium-rich cuticles form a dark envelope. Generally, metamorphosis is completed within 2 weeks and males often emerge earlier than females [38], [34]. After emergence, the young adults take off a few minutes after they have revealed their wings. Two to three days after emergence, they start to mate and the cycle starts again.

Adults: they do not feed as their mouthparts are atrophied. They need warmth (26°C optimum temperature) and light to fly and mate. The adult fly lives for 5 to 8 days [36], [39]. The complete cycle of the black soldier fly varies between 40 and 45 days [39] and is summarized in **figure 2.**

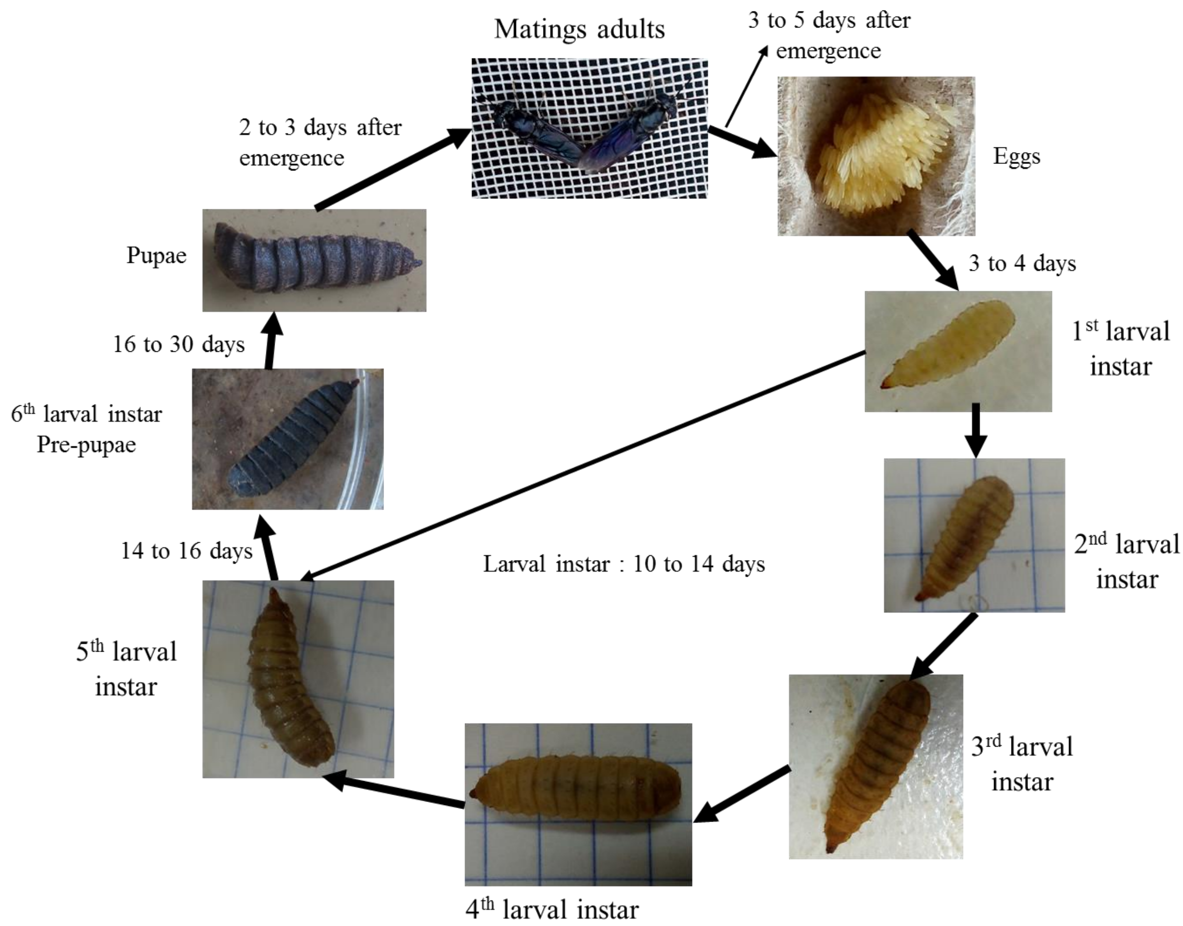


Fig. 2. Life cycle of black soldier fly (Sankara, 2022)

6 Production Of *H. Illucens* And *M. Domestica* Larvae And Rearing Of Adults

The production of maggots by natural oviposition is easy and economical. It requires substrates, containers, attractants and water (**Table 1**).

Production substrates: they can be made up of organic residues of animal origin (poultry manure, pig manure, small ruminant dung, rabbit droppings, ruminant rumen contents, cow dung,...) or of plant origin (maize, rice, soybean bran, cotton cake, brewery waste, local beer waste, rotten fruit and vegetables, household waste,...) or even mixtures of substrates [27], [28], [40], [41], [42], [43]. Attractants such as animal blood, fish waste, non-consumable meat, fermented "soumbala" (*Parkia biglobosa* seed), and rotten mangoes can be used [43], [44], [45]. The authors [27] identified about 30 substrates and/or attractants from agro-pastoralists who used them to produce or collect maggots. Some agro-pastoralists just observed the developing larvae in these substrates.

Production containers: any kind of container can be used for maggot production. These include plastic, iron, aluminium and terracotta [46], [47]. Some also use plastic bags, plastic fiber grain bags, pits, cement bins as production containers. Others spread the substrates directly on the ground to produce maggots [44].

6.1 Production Of *H. Illucens* And *M. Domestica* Larvae In The Natural Environment

The method of producing larvae consists of putting a given quantity of substrate in a container and mixing it with 70% water. This wet substrate is exposed to the flies' oviposition in the sun and sheltered from bad weather. The device is either covered immediately with a bag or tree leaves, leaving small openings for the flies to pass through, or left uncovered until the day of use. After three to seven days, housefly maggots can be harvested [11], [26]. As for black soldier fly larvae, it will take about 14 to 21 days for them to reach their maximum development [48]. In addition to this, an oviposition support must be placed on the substrates such as pieces of corrugated cardboard, piles of wood or leaves as soldier flies do not lay eggs directly on the substrates. They lay eggs between gaps or crevices next to organic matter [32]. Maggots are used either directly in a fresh state or dried and incorporated into rations to feed monogastric animals, especially chicks.

Tableau 1. Material and conditions for the production of fly larvae

Species	*Musca domestica*	*Hermetia illucens*
Production	Harvest stage: larvae Larval cycle: 3 -7 days Ideal temperature: 25-30 °C	Harvest stage: larvae and prepupae Larval cycle: 14 - 21 days Ideal temperature: 25-31 °C.
Nutrient substrates	Omnivorous: organic waste of all kinds, animal and human excrement, plant waste Examples: poultry droppings, pig manure, rotten fruit, cow dung, small ruminant dung, rabbit droppings	Omnivorous: organic waste of all kinds, animal and human excrement, plant waste Examples: corn bran, rice bran, soybean bran, cotton cake, brewery waste, local beer waste, rotting fruit and vegetables, household waste
Attractants	Animal blood, fresh fish waste, soumbala, rotten mangoes, non-edible meat	Maize bran, rice bran, soumbala, fresh fish waste
Production containers	Plastic containers Terracotta containers	Iron or aluminium containers Terracotta containers
References	[11], [26], [43], [46], [47], [49]	[33], [40], [41], [42], [49]

6.2 Breeding Of Flies, *M. Domestica* And *H. Illucens* / Egg Collection

Housefly (*M. domestica*) rearing consists of maintaining adults in confinement to obtain eggs that are placed directly into suitable substrates for hatching. Houseflies are kept at very high densities in controlled environments (temperature, humidity and light) in rearing rooms and placed for breeding in cages of varying volumes. For example, [17] tested 150 flies in a 0.04 m^3 cage; [50] tested 25,000 flies in a 0.7 m^3 volume cage while [51] tested 4.8 million flies in a 48 m^3 cage. For efficient adult reproduction in these different volumes, care should be taken to control the densities used with a sex ratio of one male to one female that can vary from 5.6 adults per cm^3 to 2.8 adults per cm^3 [50]. In order to accelerate the maturation of the genitalia, the adults are fed with various sugar solutions whose nutritional value will influence fecundity. Eggs are laid on various oviposition devices filled with attractants, e.g. pig slurry [50] or fermented wheat bran [52]. Egg production depends on the oviposition substrate used.

The black soldier fly does not need to feed, it just needs a water source to stay hydrated. It needs natural sunlight to reproduce, an optimal temperature between 25 and 32°C and a relative humidity between 30 and 90°C [53]. Under natural conditions, reproduction of *H. illucens* occurs year-round in the tropics, whereas it is limited to a few generations in warm temperate regions [35]. The sustainability of the *H. illucens* population is strongly determined by the success of mating and reproduction, which is influenced by nutrient storage during the larval period [35]. During the rearing period, the larval stages are quite easy to maintain, but achieving successful mating is difficult as specific conditions are required [54]. Several studies have shown that mating success and reproductive behaviour in *H. illucens* are influenced by abiotic and biotic factors, such as light intensity, relative humidity, ambient temperature, cage size and space, and density of adult flies in the cage [29], [35], [54], [56]. Mating periods are regulated by light intensity while oviposition depends on humidity and temperature [35]. It was reported that oviposition is favoured by temperature above 26°C allowing the development of artificial rearing systems to produce *H. illucens* throughout the year in temperate regions [35].

Two days after mating, females are ready to lay eggs at an oviposition site if volatile organic compounds are released from the surrounding decaying organic matter [58]. Eggs are laid between dry interstices near a moist food resource that will serve as food for future larvae [35]. The reproduction of *H. illucens* was the subject of several studies and rearing methods in natural, semi-artificial and artificial environments was developed and optimized [29], [54], [57], [58]. In an artificial environment [59] obtained mating and fertilized egg laying with newly emerged *H. illucens* under quartz iodine artificial lighting, while [29] also showed that rearing was possible and effective in a low volume (0.02 m^3) cage under LED artificial lighting [29], [57], [59] studied the influence of density in high-volume rearing cages for black soldier fly in a semi-artificial environment (controlled greenhouse with sunlight). They found no increase in oviposition and egg weight for different cage sizes at a fixed density. However, an increase in density produced more eggs, suggesting that higher densities are more productive. Also, [60] reported that specific wavelengths in LED lighting (LED UV: B: G ratio = 1: 1: 3) could stimulate the eyes of black soldier fly and ensure reproduction and egg fertility. This was confirmed by [55] who pointed out that LED light was the best light to promote fly longevity in small rearing cages compared to fluorescent and halogen lamps.

6.3 Larval Extraction Methods

Several methods of maggot extraction have been described in the literature. The authors [61] tested the "flotation" method, which consists of using water and a 3 x 3 mm mesh sieve to collect the larvae from the water surface. The flotation method was better than the sieve method alone for extracting larvae [18]. However, the latter method was used by [26] and [44]. It gave satisfactory results than the sieve method. Indeed, [44] showed that for small-scale maggot production systems, the sieve method is faster, more efficient and allows the harvesting of almost all maggots, but this method requires more effort, while the colander method is slow, has a lot of maggot loss after harvesting (23.05% to 77.10% of maggots harvested) and is dependent on the substrates and the size of the maggots. However, for large maggot production systems, an automatic maggot extraction system is needed to be more efficient. With this in mind, [62] developed an extractor. This extractor contains a 2 x 2 mm mesh screen through which the larvae pass into an inclined container that allows the larvae to be purified. The mixture is spread out in the screen and exposed to the sun for a maximum of 45 minutes to allow the migration of almost all the larvae from the substrate.

Another method described in the literature is the self-harvesting method which is suitable for black soldier fly larvae [53]. The device is designed to make use of the larvae's property to climb slopes once its larval cycle is complete. This allows the device to operate semi-continuously: organic waste is introduced daily, and the device is emptied of spent substrate every month. The devices vary from one person to another but have the same characteristics: a tray where the substrate will be deposited and an inclined plane (between 25 and 45°) leading to the collection container that does not fill up in case of rain [53].

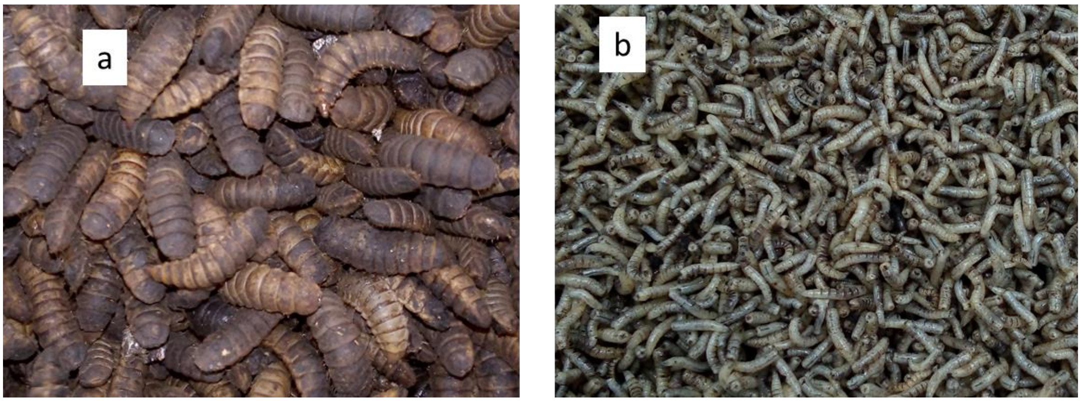
6.4 Quantity Of Maggots Produced And Factors Influencing This Production

The quantity of larvae produced varies according to the period of the year, the nature and surface area of the container, the temperature and humidity of the environment, the type of substrate used and the preference of the substrate by the flies [11], [15], [26], [43], [64] (**Table 2**).

Tableau 2. Substrates productivity in selected West African countries

Production substrates	Countries	Quantities of larvae produced (grams)	References
Larvae of *Musca domestica*			
Poultry manure (1 Kg)	Burkina Faso	86,06 à 239	[26]
Poultry manure (8 Kg)	Burkina Faso	472,3 ± 245,7	[18]
Small ruminant dung with fresh fish waste (1 Kg)	Burkina Faso	144.70	[47]
Mixture of corn bran and poultry manure (1 Kg)		124.65	
Mixture of cow dung and poultry manure		73.70	
Corn bran and coagulated blood (1 Kg)	Burkina Faso	254.3	[45]
Pig manure and coagulated blood (1 Kg)		199.8	
Rumen content with fresh fish waste (1 Kg)		121.5	
Poultry manure alone (1 Kg) Sheep manure and coagulated blood (1 Kg) Poultry manure and coagulated blood (1 Kg)	Mali	124 à 144	[63]
Corn bran (1 Kg) Seed cake (1 Kg)	Bénin	55.6 44.5	[62]
Mixture of soybean bran and corn Hull (1 Kg)	Bénin	23.83 ± 1.01	[64]
Mixture of soybean bran and corn bran (1 Kg)		23.42 ± 0.65	
Corn Bran (1 Kg)		19.53 ± 0.57	
Larvae of *Hermetia illucens*			
Mixture of soybean bran and corn Hull (1 Kg)	Bénin	14.45 ± 0.29	[64]
Mixture of soybean bran and corn bran (1 Kg)		11.84 ± 0.15	
Corn Bran (1 Kg)		12.86 ± 0.69	
Poultry manure (0.5 Kg)	Ghana	23.4 ± 3.4	[65]
Fruit waste (0.5 Kg)		30.4 ± 2.1	
Millet porridge (0.5 Kg)		46.4 ± 3.4	
Pig manure (0.5 Kg)		59.8 ± 4.5	
Pito mash (0.5 Kg)		44.0 ± 4.0	
Roots and tubers (0.5 Kg)		31.9 ± 2.4	

The authors [26] showed that insufficient moisture and excess water can be limiting factors for maggot mass production. Furthermore, increasing the amount of substrate per vessel does not necessarily imply an increase in yield, but that an optimal amount of substrate must be found depending on the dimensions of the opening of the container used [26]. The rainy season is more favourable to increase larval production than the dry and hot season. Therefore, in the dry season, the substrates can be double covered to reduce water loss through evaporation. In the cold season, covering substrates in this way can create an adequate temperature condition for good egg hatching and faster larval development [26] (Photo 3a and b).



Photos 3: a) Black soldier fly larvae; b) Housefly larvae

6.5 METHODS OF DRYING LARVAE

For drying larvae, [47] showed that exposing them to the sun on bags, black plastic or metal trays allows them to be dried in two or three days depending on the quantity of maggots and the solar intensity. In Mali, [63] recommended sun drying in the dry season, but in the rainy season they suggested that the larvae should first be placed in a hot pan for a few minutes to accelerate drying. It has been reported that the larvae can also be roasted over low heat until completely dried (about 45 min) or oven dried [47]. The authors [66] showed that dried maggots can be stored at room temperature for 30 days without deterioration.

7 NUTRITIONAL VALUES OF MAGGOTS

Both *M. domestica* and *H. illucens* larvae can be used as a protein source for fish, poultry or pigs. The use of *H. illucens* larvae in fish and shrimp feed has been extensively tested [67], while this is less the case for *M. domestica* larvae. *Musca domestica* larvae and pupae have a higher crude protein content and lower lipid content than those of *H. illucens* [9]. Another different composition is the abundance of lauric acid in *H. illucens* larvae and it's near absence in *M. domestica* larvae [68]. This difference may be an advantage for the use of *H. illucens* larvae compared to *M. domestica* larvae, as studies have shown that this fatty acid is important for the health of the animals that consume it [69] and is a suitable source of lipid in poultry diets [70], [71]. However, when *H. illucens* larvae are used commercially in feed, a defatting step is usually included to improve their suitability as an ingredient [69]. The digestibility of *H. illucens* pupae is lower than for *M. domestica* pupae or *H. illucens* larvae, when used as feed for broilers, pigs, dogs or cats, probably due to the highly mineralized exoskeleton. Dried *M. domestica* larvae are small and can be added directly to feed, whereas dried *H. illucens* larvae may need to be ground first, which may be a disadvantage in developing countries [49]. In any case, the amino acid profile of these two fly species is similar to that of fishmeal, which is the conventional standard in aquaculture [72].

Maggots can provide between 34% and 60% protein and about 4% to 40% lipids [18], [73]. However, their nutritional profile varies according to the substrates used for their production. **Table 3** shows some values of protein and lipid content in maggots (% of dry matter) according to the substrates used.

Tableau 3. Protein and fat content of maggots according to some production substrates

Production substrates	Larva of *Musca domestica*		Larva of *Hermetia illucens*	
	Protein content in % DM	Fat content in % DM	Protein content in % DM	Fat content in % DM
Poultry manure	49	4	42	35
Pig manure	58	17	43	33
Rumen content	49	21	-	-
Cow dung	59	17	34-35	21
Horse manure	-	-	41	13
Brewery waste	-	-	37-45	27-39
Fruit and vegetable waste	-	-	38	42
Municipal solid waste	-	-	36-46	25-39
Animal manure	-	-	42-44	31-35
Vegetable waste	-	-	40	37
Sources	[5], [74]		[36], [75], [76], [77]	

Legend: DM = Dry Matter

The chemical composition of some insects has been published by [9] and [78] In general, black soldier fly larvae have high crude protein levels, ranging from 40 to 44% crude protein (% dry matter). Housefly larvae have protein levels ranging from 45 to 55% dry matter. These levels can reach 70% for the silkworm (*Bombyx mori*) (**Table 4**). Their fat content varies between 12 and 25%, and can become very high, up to 40% DM in *Tenebrio molitor* larvae. Nutrient concentrations change dynamically during metamorphosis, as shown by [79] with the example of the black soldier fly.

Tableau 4. Chemical composition of M. domestica and H. illucens larval meals compared to other protein sources [7], [80]

Sources of nutrients	Ashes (% DM)	Crude Fat (% DM)	Crude Protein (% DM)	Total Lysine (% DM)	Total Methionine (% DM)
Musca domestica	10,1 ± 3,3	18,9 ± 5,6	50,4 ± 5,3	3,07	1,11
Hermetia illucens	20,6 ± 6,0	26,0 ± 8,3	42,1 ± 1,0	2,78	0,88
Tenebrio mollitor	3,1 ±0,9	36,1 ± 4,1	52,8 ± 4,2	2,86	0,79
Bombyx mori	5,8 ± 2,4	25,7 ± 9,0	60,7 ± 7,0	4,25	2,12
Soybean meal	7,0	2,2	50,0	3,05	0,67
Fish meal	16,3	10,1	71,8	5,31	1,94

Legends: %DM = percentage of dry matter

8 Zootechnical Performance Of Animals Fed With Maggots

The maggots produced represent an alternative source of protein available for animal feed. Several studies have shown their ability to efficiently replace conventional protein sources, especially fishmeal, in poultry feeds without decreasing their performance [4], [5], [7], [14], [49]. In Burkina Faso, studies have shown that the best time of day to supplement with maggots in chickens is around 12: 00. However, in *Guinea fowl* maggots can be supplemented at any time of the day [5], [7]. In addition, chickens fed with fresh maggots provided higher carcass yields than those fed a maggot-free ration (71.63% versus 68.61%). On the other hand, chicks fed with fresh maggots in intensive rearing had higher weights (788.84 g) than the control (617.91 g) [18]. In Benin, [81] showed that the use of fresh maggots as a feed supplement increases the number of eggs laid by free-ranging hens, reduces the laying interval and improves farmers' income. This would allow an optimal use of maggots, which is an alternative to the high cost of conventional protein sources used in poultry farming [81]. Also, [82] reported that the incorporation rate of 11.0% maggot meal results in better egg-laying growth of Barbary ducklings and at the same time reduces their mortality rate to less than 6%. In Ghana, *M. domestica* larvae are used as animal protein sources for poultry, pigs and fish [14]. In Niger, [83] report that substituting 50% fresh or dried maggots for fishmeal in the diets of growing local chickens had no effect on their body weight, but increased growth rate and feed consumption. It has been shown that dried maggots can replace groundnut meal in chicken diets without affecting their usual performance [84]. Maggots can replace 60% of soybean meal and 33% of fish meal in broiler diets without negatively affecting their zootechnical performance [85]. Current studies have shown that it is possible to replace up to 10% of the soybean in the diet of laying hens with black soldier fly maggots, without affecting the laying performance and physical health of the hens [86]. A recently published report indicates that the inclusion of dried black soldier fly prepupae meal improves egg weight and shell thickness compared to a diet without prepupae meal. However, no difference in production performance was observed [87]. For rainbow trout, rations based on black soldier fly maggots reared in omega-3 enriched substrates give comparable developmental results compared to conventional fishmeal rations [88]. In experiments conducted on broiler quails, *Coturnix coturnix japonica,* showed no difference between the control feed and two proportions of *H. illucens* larval meal on productive performance, meat weight and carcass yield [70], [89]. Supplementation with *H. illucens* larvae (50%) or total replacement of soybean meal in the diet of laying hens had no impact on hen health or performance and little or no effect on the eggs themselves [70], [90]. Furthermore, *H. illucens* larval meal has successfully replaced other conventional protein sources in the diet of Nile tilapia [91], *African catfish* [92] and many other fish species. Similarly, the inclusion of *H. illucens* larval meal in the diet of *Oreochromis niloticus* did not have negative effects on body weight gain, feed conversion and specific growth rates [10]. The authors [93] also found that the use of *H. illucens* larvae as a partial or total replacement for fishmeal increased the average daily gain of finishing pigs. Final body weight, fasting weight and carcass weight were significantly higher in the 50% and 100% *H. illucens* larvae supplemented groups than in the unsupplemented and 25% supplemented groups [93].

9 Ecological Significance Of Maggots And Maggot Waste

9.1 Waste Treatment

Maggots are used in the processing of animal and plant organic matter, organic household waste and brewery co-products [10], [29], [94]. Compared to other farmed insect species, the ability of maggots to degrade organic waste is recognized as one of the best [88]. Indeed, BLACK SOLDIER FLY maggots are able to reduce the total mass of organic household waste by 65.5 to 78.9% and at the same time produce protein-rich larvae [40]. The volume of organic matter after consumption by black soldier maggots is reduced by between 50 and 80% [48].

9.2 Reduction Of Pathogens

Maggots transform the nutrient substrate in which they live. They contain high levels of lauric acid, which has an antimicrobial effect on intestinal pathogens [95]. As a result, they are able to reduce the amount of pathogenic bacteria (*Escherichia coli, Salmonella enterica*) present in manures [41], [96].

9.3 Production Of Organic Fertilizers

Residues from maggot production can be used as a natural organic amendment to fertilize crops [97] A study was conducted in the west of Burkina Faso to assess the effects of poultry litter and maggot production residues on soil chemical fertility and maize yield. The results showed that the organic substrates did not have a significant effect on soil chemical parameters. However, the use of maggot production residues induced an 84% increase in maize yield compared to natural soil fertility [98] showed that maggot production residues could be combined with other organic substrates on farms with the prospect of reducing fertilizer use. Furthermore, [99] showed that composting organic waste using maggots is better than the current conventional method.

9.4 Biofuel Production

The lipids produced by black soldier fly larvae are good candidates for biofuel and bio-lubricant production [97]. About 43.8 g biodiesel could be produced from 2000 black soldier fly larvae [58]. Indeed, studies by [100] on the fatty acid profile of black soldier fly larvae confirm that the fats produced are suitable for biofuel production.

10 Conclusion

Fly maggots can be easily produced on decomposing organic waste and successfully used to partially replace conventional protein sources such as fishmeal, soybean and oilcake in rations of animals fed without affecting their growth. The methods of production and use of these maggots are well documented and available to all. An adoption of the methods of production and use of maggots in animal feed can therefore contribute to reduce the cost of production for agro-pastoralists. This study adds to the literature on maggot production, extraction and drying methods, rearing of adult flies and chemical composition of maggots as well as zootechnical performance of maggot-fed animals. A wide range of substrates and containers are available to producers for better optimization of maggot production.

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Conflicts Of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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