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PROSPECTS FOR USING *Hermetia illucens* LARVAE IN THE DIET OF FARM ANIMALS: A REVIEW

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ABSTRACT: *Hermetia illucens* larvae is a promising raw material as an alternative ecological raw material for obtaining feed ingredients. The aim of this review is to gain a comprehensive understanding of the current state of research in this topic by critically analyzing existing studies. Based on the review, recommended doses of defatted *Hermetia illucens* larval meal in the diet were identified. Replacing fish meal with *Hermetia illucens* larval meal in the amount of 25 and 50% ensures stable weight gain and high-quality fish products. When feeding largemouth bass and red hybrid tilapia, the recommended proportion of replacing fish meal with insect meal is no more than 30%. Substitution of vegetable protein with *Hermetia illucens* protein in the diet of sea bass in the amount of 40% improves the histological condition of intestinal tissue. Replacing linseed fat in the amount of 30 and 60 g/kg of feed with fat from *Hermetia illucens* larvae in feeding rabbits revealed a negative effect on meat quality: a high content of saturated fatty acids is observed. As a positive effect of *Hermetia illucens* fat, a decrease in meat oxidation can be noted. The use of full-fat *Hermetia illucens* meal in the diet of piglets should be limited to 2%. However, the protein of the *Hermetia illucens* larvae has great potential and can be partially replaced in combination with the protein of other insects. A number of studies presented in this review have proven the economic efficiency of using *Hermetia illucens* larval meal in feed production: the cost of *Hermetia illucens* larval meal is lower than the cost of fish meal by 0.35 USD/kg, which increases the profitability of using this type of raw material by 25%. The problems of the widespread use of Hermetia illucens larval meal in animal feeding have been identified, which consist in the low attractiveness of meat and fish products grown on feed using insects. In order to reduce the negative attitude of consumers to such food products, it is necessary to increase public awareness of the environmental friendliness and safety of using such components in animal feeding.

Keywords: Fat sources, Feed components, *Hermetia illucens*, Insect flour, Protein sources.

INTRODUCTION

Fishmeal and fish fat are the main sources of animal protein and fat in compound feeds for various animals, birds and fish. Its deficit, constantly fluctuating quality and the lack of implemented alternatives make the compound feed industry highly dependent on this product (Muin and Taufek, 2024). A topical issue in the field of feed production is the introduction of alternative ecological feed ingredients. Insects have long been considered by the scientific and industrial community as a worthy alternative to fishmeal and fish fat (Vastolo et al., 2024). Silkworms, mealworms, housefly larvae, *Hermetia illucens* larvae, grasshoppers, termites, common mosquitoes, etc. are considered as a source of feed protein and fat (Henry et al., 2015). The authors (Téguia al., 2002; Henry et al., 2015; Yu, et al., 2020; Wendin and Nyberg, 2021; Giotis and Drichoutis, 2021; Pahmeyer et al., 2022; Nampijja. et al., 2023; Roccatello R et al., 2024; Muin and Taufek, 2024) consider their advantages (highly reproducible, rich amino acid composition, high digestibility, etc.) and disadvantages (for example, the unattractiveness of food products grown on feed containing insects). Therefore, meal from insects (houseflies) was used in the study (Téguia et al., 2002). According to the results of Téguia et al. (2002), it was found that feed conversion and weight gain in the control and experimental groups were almost the same. However, the authors noted that in the experimental group, whose diet included meal from insects, an increase in the liver and goiter was observed. The authors conclude that it is necessary to analyze the toxicity of meal from insects, in particular, flour from housefly larvae, since most likely it was the cause of negative changes in the organs of birds.

Over the past few years, the number of studies on the use of the *Hermetia illucens* fly larvae as an alternative ecological raw material for obtaining feed ingredients has increased significantly (Barragan-Fonseca et al., 2017; Lee et al., 2020; Sadykova et al., 2021; Dong et al., 2024; Daniso et al., 2024; Zhan et al., 2024; Maltseva et al., 2024). *Hermetia illucens* larvae flour (Muin and Taufek, 2024) has a lower feed conversion ratio (1.69) and a higher protein efficiency ratio (1.97) compared to fishmeal, which has a feed conversion ratio of (2.43), protein efficiency ratio (1.37) when fed to tilapia. Despite the significant results obtained in this area, a comprehensive understanding of the effects of alternative ecological feed ingredients on the animal organism and the identification of further development paths

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are needed. The aim of this study is to gain a comprehensive understanding of the current state of research in this topic by critically analyzing existing studies.

Useful nutrients of the *Hermetia illucens* larvae

In the studies (Sealey et al., 2011; Park, 2016; Liland et al., 2017; Ewald et al., 2020; Lee et al., 2020; Sadykova et al., 2021; Tuichiev, 2023; Nampijja et al., 2023; Rudoy et al., 2023; Zhan et al., 2024), the authors noted the beneficial properties of the *Hermetia illucens* larvae, examining each of the components in more detail: protein and amino acids, fat and fatty acids, vitamins, chitin, peptides. To compare different studies on similar parameters, let's look at each of them in more detail.

Protein and amino acids

The *Hermetia illucens* larvae has an amino acid composition similar to that of fish meal (Tuichiev, 2023) and chicken egg white (Sadykova et al., 2021). The protein content and amino acid composition may differ depending on the substrate on which the larvae are raised. When grown on animal waste, larvae will have a lower protein content than larvae grown on food production waste, especially with a high protein content (Sealey et al., 2011). Therefore, the choice of substrate will have a significant impact on the quality of the product, as well as the cost price. The predominant amino acids in the protein of the *Hermetia illucens* larva are glutamic and aspartic acid and leucine (Sadykova et al., 2021). The protein is highly digestible (Muin et al., 2024) and can be used in feeds both in starter feeds and in grower feeds (Nampijja et al., 2023).

Fat and fatty acids

Sealey et al. (2011) investigated the change in fatty acid composition depending on the substrate. Thus, when growing larvae on cow manure, the predominant fatty acids were: lauric (12:0) 23.6%; palmitic (16:0) 19.8%; oleic acid (18:1n-9) 22.7%. When adding fish by-products - waste from fish processing plants - to this substrate, the amount of lauric acid (12:0) sharply increased 37.1%; palmitic (16:0) slightly decreased 17.3%; and oleic acid (18:1n-9) 18.8%. In another study by Caligiani et al. (2018) the predominant fatty acid was also lauric acid (12:0) more than 40%. Lauric acid has a bactericidal effect, suppressing the development of pathogenic microflora (Setianto et al., 2017). This is confirmed by the study (Kumar et al., 2021; Biasato et al., 2022), where researches came to the conclusion that the fat of the *Hermetia illucens* larva has an immunostimulating effect and helps prevent intestinal enteritis in rainbow trout (*Oncorhynchus mykiss*) caused by soybean fat, which is currently used in feed. Lauric acid also has a positive effect on the microbial population of the intestines of animals, their vital organs and blood composition (Khan et al., 2021; Zhan et al., 2024). When analyzing the fat of the *Hermetia illucens* larvae (Cruz et al., 2023) a volatile compound, limonene, was discovered, which is used in the pharmaceutical, cosmetic and food industries due to its antioxidant and insecticidal properties. Ewald et al. (2020) conducted research on the effect of substrate on fatty acid composition. It was found that regardless of the substrate, the main fatty acid is lauric acid (saturated fatty acid). In this regard, researchers concluded that it is impossible to completely replace fish fat with fat from the larvae of *Hermetia illucens*. This is supported by another study (Kumar et al., 2021), where 16% of fish fat was replaced by *Hermetia illucens* larval fat. Histological examination of the liver revealed hyperplasia of the bile ducts, which may indicate excessive release of bile to facilitate lipid digestion (especially containing semi-saturated fatty acids, which is lauric acid). Therefore, *Hermetia illucens* larval fat can only partially replace fish fat due to the high concentration of lauric acid.

Vitamins

The larvae contain various fat-soluble vitamins and carotenoids (Liland et al., 2017; Sadykova et al., 2021; Papin et al., 2025), that have a positive effect on the digestibility of compound feed and participate in vital processes. According to Sadykova et al. (2021), the amount of carotenoids is 0.23 mg/100 g, Vitamin E — 3.1 current. equiv./100 g, Vitamin B1 (Thiamine) — 53 μg / 100 g. In Liland et al. (2017), the content of Vitamin E in the control (when hatched on a substrate — crushed wheat) was 53 mg/kg^{-1}, when seaweed was added to the substrate in an amount of 50%, the content of Vitamin E increased 4 times and amounted to 187 mg/kg^{-1}, with 100% replacement of the substrate with seaweed, the content of Vitamin E was 249 mg/kg^{-1}. Papin et al. (2025) argue that in order to obtain larvae with a given set of essential vitamins and carotenoids, it is necessary to adjust the composition of the substrate. In addition, the researchers of this study found that *Hermetia illucens* larvae are able to bioaccumulate vitamin E and carotenoids. To achieve higher concentrations of beneficial vitamins and carotenoids, additional research on insect cultivation is necessary.

Chitin

Chitin is a valuable feed raw material, has a positive effect on weight gain, has a negative effect on pathogenic microorganisms. Shaikhiev et al. (2022) determined the dynamics of changes in the chitin content in the insect during growth: larval stage — 3.6%, prepupal stage — 3.1%, puparia stage — 14.1%, imago stage — 2.9%. In other studies, the chitin content in the larvae was 3.85% (Smets et al., 2020), 7.8% (Soetemans et al., 2020), and 4.65% (Yu et al., 2020).

This difference may be due to the substrate on which the larvae were raised. Kim et al. (2025) presented the results of the antitumor effect on the animal's body (laboratory mice were used in the study), chitin helps to reduce the mass of adipose tissue in obesity and increases the diversity of intestinal microbiota with beneficial microorganisms, increases the number of lactobacilli. In this research, chitin obtained from *Hermetia illucens* was introduced into the stomach every other day using a probe as a chitin solution at a dosage of 10 mg/kg. When examining the larvae for protein content, the indicators are overestimated due to the presence of non-protein nitrogen in insects. Non-protein nitrogen also includes chitin. In the standard method, protein content is calculated by determining the total nitrogen content and using the nitrogen-to-protein conversion coefficient. This coefficient is 6.25. Janssen et al. (2017) determined the coefficient to be 5.60. These studies obtain indicators for identification of protein content in insects, without overestimating them.

Antimicrobial peptides

Lee et al. (2020) and Peng et al. (2024) discovered antimicrobial peptides in the hemolymph of the *Hermetia illucens* fly larvae. They have antibacterial properties and a wide range of effects on various pathogenic microorganisms. Cecropins, natural broad-spectrum peptides, are given special attention due to their high efficiency. This peptide was first obtained from the pupa of the giant silkworm. Currently, insects are the source of this peptide. It is noteworthy that the *Hermetia illucens* larvae contains more than 36 genes (Lee et al., 2020) that encode cecropins. For comparison, the larvae of the *Musca domestica* fly contain only 12 genes that encode cecropins. Cecropins have shown their effectiveness in the fight against gram-positive bacteria, including *Escherichia Coli*, *Acinetobacter baumannii* and *Klebsiella pneumonia*, which causes pneumonia.

The research conducted by Kumar et al. (2021) demonstrated that the effectiveness of using flour from the larvae of the fly *Hermetia illucens* as a component that reduces the degree of inflammation when using soy flour, which may contain anti-nutrients and cause inflammatory processes in the animal's body. Peng et al. (2024) note that peptides obtained from the larvae of *Hermetia illucens* can be used in the development of industrial antimicrobial drugs.

REVIEW OF THE RESULTS OF STUDIES ON FEEDING ANIMALS, BIRDS AND FISH WITH PROCESSED PRODUCTS OF THE LARVAE OF *Hermetia illucens*

A review of studies on the use of defatted *Hermetia illucens* larval meal, fat and full-fat *Hermetia illucens* larval meal was conducted. The main results are summarized in Table 1.

The results of a review of scientific studies on the use of *Hermetia illucens* in feeding various animals, birds and fish allowed us to determine the recommended doses of introducing low-fat flour from the larvae of *Hermetia illucens* into the diet. Skimmed flour from the larvae of *Hermetia illucens* can replace fish meal without negative consequences in quantities up to 30% (Sealey et al., 2011; Li et al., 2021; Nampijja et al., 2023; Dong et al., 2024; Daniso et al., 2024; Muin and Taufek, 2024; Marcheva G et al., 2024). Such a replacement ensures stable weight gain and high-quality products. The increase in the proportion of defatted meal from the larvae of *Hermetia illucens* should be done individually depending on the species and age of the animal.

For fish, the recommended proportion of fish meal replacement with flour from *Hermetia illucens* insects is from 30 to 40% (Sealey et al., 2011; Dong et al., 2024; Daniso et al., 2024; Muin and Taufek, 2024). For broiler chickens, the replacement of fish meal with flour from *Hermetia illucens* was 540 g/kg (Nampijja et al., 2023). In the feed recipe for Chinese soft-shelled turtles, fish meal can be replaced with defatted *Hermetia illucens* larval meal in an amount of no more than 10%. The researchers had note that the negative impact of higher doses of *Hermetia illucens* larval meal may be associated with the high chitin content and the increased protein content in the feed due to it, when using the standard nitrogen-to-protein conversion factor of 6.25. This is confirmed by another study (Yu et al., 2020), where the authors note the inability of monogastric animals (pigs, horses, poultry, etc.) to digest chitin, and therefore the apparent digestibility of nutrients is overestimated. An increase in the amount of low-fat flour from *Hermetia illucens* larvae in the diet of animals causes negative consequences: there is a decrease in growth (Li et al., 2021; Dong et al., 2024), deterioration of blood parameters (Marcheva et al., 2024), development of intestinal dysbiosis (Dong et al., 2024). The use of fat from the larvae *Hermetia illucens* has a negative impact on the quality of meat – the content of saturated fatty acids increases, in addition, blood parameters deteriorate: there is a violation of cholesterol metabolism and the formation of blood clots (Zotte et al., 2018). As a positive effect of *Hermetia illucens* fat, a decrease in the oxidizability of meat can be noted.

The use of full-fat flour from *Hermetia illucens* in the diet of piglets should be limited to 2%. The high fat content of *Hermetia illucens* meal has a negative impact on the vital organs of the animal: the size of the liver and small intestine increases. This is consistent with the results of numerous studies (Sealeyet et al., 2011; Zotte et al., 2018; Ewald et al., 2020; Kumar et al., 2021), where the authors note the high content of saturated fatty acids, which increases the load on the digestive organs for its digestion. Thus, according to numerous studies, the prospect of using *Hermetia illucens* larval meal as a partial replacement for fish meal has been confirmed. *Hermetia illucens* larval meal has a beneficial effect on the growth and development of animals, their survival. But, in addition to these indicators, an important economic indicator is one that determines the feasibility of using this raw material in feed production (Vastolo et al., 2024).

Table 1 — Average Value of lignin parameters from sugarcane bagasse					
Object of feed testing	**The substrate on which the larvae were grown**	**Proportion of larvae added (whole, larvae meal or fat)**	**Evaluated indicators**	**Results**	**References**
Oncorhynchus mykiss	Dairy cow manure (experimental group 1) and dairy cow manure with fish by-products added in an amount of 25 to 50% (experimental group 2	25 and 50% replacement of fish meal on defatted flour from HI larvae	Weight gain, hepatosomatic index, intraperitoneal fat and muscle mass to total body mass ratio, fish fillet appearance, amino acid composition and fatty acid composition	Weight gain in fish and hepatosomatic index in the control and experimental group 2 did not differ significantly, in contrast to the experimental group 1; the highest amount of intraperitoneal fat was observed in the control; the ratio of muscle mass to body weight in all the studied samples had an insignificant difference; assessment of the appearance of the fillet did not reveal a significant difference in all the tested samples; replacement of fish meal with experimental group 2 or experimental group 1 in the amount of 25 and 50% does not have a negative effect on trout growing	Sealey et al. (2011)
Micropterus salmoides	No data	10, 20, 30 and 40% fish meal replacement on defatted flour from *HI* larvae	Rate of weight gain, morphology and intestinal microbiota, amino acid composition and fatty acid composition of fish meat	The efficiency of the experimental feed was observed when replacing fish meal with *Hermetia illucens* larval meal (HI) in an amount of no more than 30%. When replacing 40%, a decrease in the height of the villi, an increase in their width and an increase in the number of goblet cells were observed in the intestinal morphology, which contributes to intestinal dysbacteriosis. The rate of weight gain for the control sample and samples where fish meal was replaced by 10-30% was equally high (723-749%). In the experiment where 40% HI was present, the growth rate dropped sharply (624%). The content of polyunsaturated fatty acids decreased with the introduction of HI. With the introduction of HI, the amount of tyrosine and histidine increased. The introduction of HI flour did not have a significant effect on other amino acids.	Dong et al. (2024)
Sparus aurata L.	No data	20 and 40% replacement of vegetable protein on defatted flour from *HI* larvae	Histological condition of intestinal tissues	The absence of animal protein (fish meal or HI meal) in the control negatively affects the intestinal condition: moderate to severe gastritis is observed. Also, in the experiment with HI content of 20%, a mild degree of gastritis was observed. Replacing vegetable protein with HI protein in the amount of 40% improves the histological condition of intestinal tissues.	Daniso et al. (2024)
Red Hybrid Tilapia	Soybean curd residue	30% HI meal is introduced into the feed, partially replacing fish meal, soybean meal, rice bran meal and corn meal	Dry matter digestibility coefficient, weight gain, feed conversion coefficient	The body weight gain in the experimental feed was 1.4 times higher than in the control. The feed conversion ratio in the experiment was 1.7, in the control — 2.4. The dry matter digestibility ratio in the experiment was also higher (1.97) than in the control (1.37). 100% survival was observed. The addition of 30% HI flour is effective in feeding tilapia.	Muin and Taufek, (2024)
Rabbits	No data	Replacement of linseed fat with HI larval fat in the amount of 30 and 60 g/kg of feed	Degree of oxidation of meat, composition of fatty acids of meat, indicators of atherogenicity and thrombogenicity	The meat of the rabbit, whose diet included HI fat, showed significantly higher atherogenicity and thrombogenicity than the control sample. Increasing the amount of HI fat in the sample from 30 to 60 g / kg increased the level of atherogenicity, while increasing the level of flaxseed fat decreased this indicator. HI fat has a high content of lauric fatty acid (12: 0) and myristic fatty acid (14: 0). When feeding rabbits with food with HI fat, the amount of these acids also increases, which	Zotte et al. (2018)

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				contributes to an increase in atherogenicity and thrombogenicity. The meat of the rabbit, which was fed with food with flax fat, is more susceptible to oxidation than when using HI fat.	
Broiler chickens	Beer waste	Replacement of fish meal with HI meal in quantities of 250, 500, 750 and 1000 g/kg dry matter i.e. replacing fish meal with *HI* flour 25%, 50%, 75% and 100% respectively	Weight gain, feed intake, dry matter digestibility, nutritional composition of meat	Weight gain, feed intake and dry matter digestibility decreased with increasing proportion of HI meal. The authors attribute the decrease in digestibility to the chitin content. Replacing fish meal with HI meal increased the fat content and decreased the protein content. Increasing the proportion of HI meal increased the proportion of saturated fatty acids and Omega-6 fatty acids, but decreased the proportion of Omega-3. Replacing fish meal with HI meal is possible up to 540 g/kg (i.e. the possible replacement of fishmeal with *HI* flour is 54%). Such a replacement will be cost-effective and will not have a significant effect on the studied parameters.	Nampijja et al. (2023)
Pigs	No data	Replacement of soybean meal (in control 228 g/kg) with defatted meal from HI in the amount of 30, 60, 90 and 120 g/kg i.e. replacing soybean meal with flour from *HI* 13%, 26%, 40% and 52% respectively	Growth indicators and blood biochemical parameters	Replacement of soybean meal with HI flour is permissible in quantities up to 120 g/kg i.e. to 52%. At such values, growth rates and blood parameters did not change.	Marcheva et al. (2024)
Chinese soft-shelled turtles	No data	Replacement of fish meal with defatted HI meal in quantities of 5, 10, 15 and 20%	Growth indicators, biochemical index of blood serum, antioxidant properties, amino acid composition of turtle meat	The growth rates when replacing fish meal with HI meal in the amount of 5 and 10% showed no difference compared to the control. When the proportion of HI meal increased to 15 and 20%, the growth rate decreased. The authors also associate this result with the chitin content and overestimated protein levels in the feed with the standard conversion of nitrogen to protein (with a coefficient of 6.25). The fat content increased linearly with an increase in the proportion of HI meal. An analysis of the amino acid composition showed a decrease in phenylalanine, tyrosine and arginine in the experimental samples compared to the control. Blood analysis showed that with a 10% replacement of fish meal, the maximum activity of alkaline phosphatase was observed, which affects the immune response of the animal's body. The optimal proportion of replacing fish meal with HI meal is 10%.	Li et al. (2021)
Piglets	No data	Replacement of fish meal with full fat HI flour in the amount of 1.2 and 4%	Organ condition, feed digestibility	With an increase in the proportion of full-fat HI meal, an increase in the weight of the liver and small intestine was observed. The size of the remaining organs did not show significant differences. The digestibility of protein and fat decreased with an increase in the proportion of HI meal in the feed. The minimum was observed at 4%. Thus, the optimal proportion of replacing fish meal with full-fat HI meal is 2%.	Yu et al. (2020)

ECONOMIC EFFICIENCY OF USING *Hermetia illucens* LARVAE

According to Chia et al. (2019), up to 70% of livestock production costs are spent on feed, especially protein components. Recently, there has been a rapid increase in prices for fishmeal and soybean meal. This is especially true for small farms, whose budget forces them to look for alternative sources of high-quality protein at an affordable, stable price. According to Chia et al. (2019), the cost of fishmeal is 1.2 US dollars/kg, while the cost of *Hermetia illucens* meal is 0.85 US dollars/kg. This increases the profitability of using this type of raw material by 25%. Pahmeyer et al. (2022) calculated the costs of obtaining *Hermetia illucens* larvae and the payback period of an automated module for their production depending on the cost of the finished product. Thus, with the cost of larvae of 3.55 US dollars/kg, the payback period will be 5 years (the module capacity was 1.1 tons/month). The average cost of fishmeal in the world is 1.23 US dollars/kg. At this cost, the payback period will be 10 years, which is not profitable. According to Zagorovskaya (2020), for Black soldier fly meal to be in demand on the market, its cost should be 1.3-1.62 US dollars/kg. For this, the production volume should be at least 30-50 tons/month. Therefore, when scaling the automated module (Pahmeyer et al., 2022) in order to increase its capacity, the cost of production per 1 kg will be significantly reduced and will be consistent with the results presented in the work (Chia et al., 2019). An additional economic effect is the reduction in feed conversion ratio values when using BSF larval protein, which increases weight gain with the same feed consumption (Yu et al., 2020; Nampijja et al., 2023; Muin and Taufek, 2024). Thus, using *Hermetia illucens* fly larvae is beneficial both in terms of animal production and economic efficiency.

TECHNOLOGIES AND METHODS FOR OBTAINING PROTEIN FROM *Hermetia illucens* LARVAE

From a review of studies by various researchers (Table 1), it was determined that the most effective way to feed animals is to use defatted flour from the larvae of the fly *Hermetia illucens*. There are several technologies and methods for obtaining this product. To identify the advantages and disadvantages of each of them, let us consider these technologies in more detail.

The process of converting larvae into protein concentrate begins with cleaning the substrate on which they were reared by sieving and rinsing with cold water (Bußler et al., 2016; Biasato et al., 2022; Cruz et al., 2023; Maltseva et al., 2024). Next, the larvae are inactivated by freezing at minus 20 degrees Celsius (Bußler et al., 2016; Cruz et al., 2023) or by grinding and pasteurization (Biasato et al., 2022). Various methods have been used to separate the fractions.

1) The authors of the study (Bußler et al., 2016) presented several stages of fractionation: in the first stage, the protein portion was separated from the fat by pureeing the frozen mass with distilled water in a 1:1 ratio, re-freezing, freeze-drying, grinding, chemical fat extraction using a solvent (hexane) and re-grinding. A high-protein fraction was obtained from defatted flour using aqueous extraction of soluble proteins with distilled water in an alkaline medium. Next, centrifugation and protein precipitation were carried out due to acid hydrolysis. Insoluble proteins were freeze-dried and ground. Using this method, the following products are obtained: fat, defatted flour with high (water-soluble proteins) and low (water-insoluble proteins) protein content.

2) In another study (Biasato et al., 2022), after the pasteurization process, protein and fat were separated by centrifugation. Using this method, 2 fractions were obtained: fat and partially defatted protein meal. The authors noted that insect meal after such treatment can be stored for 6 months at a temperature of no more than 20 degrees Celsius, in a dry place.

3) In Cruz et al. (2023), after freezing, the larvae were again washed under running water, placed in a sodium hydrochloride solution for sterilization, then washed again under running water and placed in a boiling solution of sodium bisulfite, which acts as an antioxidant. Then the larvae were dried at a temperature of 60 degrees Celsius, crushed and sent for fat extraction. Extraction was carried out with supercritical CO_2, which is an environmentally friendly method compared to the hexane extraction method. In addition, this method speeds up the extraction process and allows preserving a large number of carotenoids in the larval fat. Using this method, 2 fractions were obtained: fat and partially defatted protein flour.

4) A mechanical method for separating the larvae into fractions is described in the work (Maltseva et al., 2024). It consists of drying the larvae, grinding them, heating the ground mass using a microwave and squeezing out the fat on a screw press. Microwave heating is used to quickly heat the raw material, reduce the viscosity of the fat and increase the intensity of its separation from the protein part, as well as for the purpose of disinfection. Using this method, 2 fractions were obtained: fat and partially defatted protein flour.

Thus, both chemical and mechanical methods can be used to obtain feed components from the *Hermetia illucens* larva. The choice of method will depend on the technical, financial capabilities and scale of production.

CONSUMER WILLINGNESS TO CONSUME FOOD GROWN ON INSECT-FED FEED

Despite the potential of using insects in feed as a high-quality, efficient and cost-effective raw material, there are limitations in the sale of finished products grown on such feed among consumers. Food products grown on feed using

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insects are less attractive than food products obtained using traditional technologies (Wendin and Nyberg, 2021; Giotis and Drichoutis, 2021; Roccatello R et al., 2024). The main reasons preventing the choice of such products are disgust and doubts about the safety of food products (Roccatello R et al., 2024). The authors state (Wendin and Nyberg, 2021; Giotis and Drichoutis, 2021; Roccatello R et al., 2024) that raising public awareness of the environmental friendliness and safety of using such components in animal feeding reduces negative consumer attitudes towards such food products. In addition, studies (Giotis and Drichoutis, 2021) note that consumers are more likely to purchase food grown using insect feed than to use insects as food. Wendin and Nyberg (2021) and Giotis and Drichoutis (2021) argue that the palatability of food products obtained using innovative feeds (insect feeds) is influenced by their taste. This factor also relates to public awareness of the benefits of such products.

CONCLUSION

Numerous studies have shown that both fish meal and insect meal play a key role in normal development, weight gain and feed efficiency. A review of the studies showed that fish meal remains a key source of animal protein and essential amino acids and cannot be fully replaced by *Hermetia illucens* larval meal. In addition, larval fat is less effective when used in animal feed, so the whole larvae can be used in animal feed only in small quantities (about 2%), especially when feeding monogastric animals. Therefore, it should be defatted to minimize the final amount of fat in the feed. At the same time, the fat of the larvae contains lauric acid, which has a bactericidal effect and has an immunostimulating effect, and a volatile compound — limonene, which has antioxidant and insecticidal properties. Such properties make the fat of the *Hermetia illucens* larvae a useful and valuable raw material both in the feed industry and in the pharmaceutical, cosmetic and food industries. The results of the studies of the economic efficiency of using *Hermetia illucens* larvae in feed production showed that larval meal can be economically advantageous when replacing fish meal. There are some differences in the results of the studies, where according to some data, the cost of *Hermetia illucens* larval meal is currently lower than the cost of fish meal, while others only determined the prospects and ways to reduce the cost of *Hermetia illucens* larval meal. This may be due to the technologies used to process the larvae into feed components, as well as the costs of growing larvae, which differ in different countries (in particular, due to climatic conditions, the cost of electricity, etc.). Therefore, one of the areas of further research is to reduce the cost of producing insect meal, in particular from *Hermetia illucens* larvae. The chitin contained in the larvae can have both positive and negative effects. Therefore, its use is limited to the feeding object. However, the protein of the *Hermetia illucens* larvae has great potential and can be partially replaced in combination with the protein of other insects, which are used as feed additives. One of the problems of its widespread use is the low attractiveness of meat and fish products grown on feeds using insects. To reduce the negative attitude of consumers to such food products, it is necessary to increase public awareness of the environmental friendliness and safety of using such components in animal feeding. This direction is fundamental in the further development of the use of insects in the feed industry. It is also necessary to continue research to improve existing technologies for processing *Hermetia illucens* larvae into feed components, reducing the cost of the final product.

DECLARATIONS

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Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

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Authors participation

T. Maltseva contributed for the write up of the study design, review and analysis of research. D. Rudoy performed supervision and editing. A. Olshevskaya performed final revision of the manuscript. M. Odabashyan reviewed and analyzed studies. V. Shevchenko critically revised the manuscript for important academic contents.

Competing interests

The authors declare that they have no competing interests.

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