



Potential Utilization of Edible Insects as an Alternative Source of Protein in Animal Diets in Poland

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Specialty section:

This article was submitted to
Nutrition and Sustainable Diets,
a section of the journal
Frontiers in Sustainable Food Systems

Received: 03 March 2021

Accepted: 20 May 2021

Published: 17 June 2021

Citation:

Gałęcki R, Zielonka Ł, Zasepa M,
Gołębiowska J and Bakula T (2021)
Potential Utilization of Edible Insects
as an Alternative Source of Protein in
Animal Diets in Poland.
Front. Sustain. Food Syst. 5:675796.
doi: 10.3389/fsufs.2021.675796

The selection of high-protein raw materials that could be utilized in the production of animal feed is limited in Poland. The aim of this study was to analyze the needs and possibilities associated with the utilization of insect protein in animal nutrition in Poland. In the future, insects could become an effective solution to meeting the nutritional requirements of a growing population. Insect protein is already used in the production of fish feed in the European Union (EU). Legislative decisions on the introduction of this alternative feed source have to be based on the results of studies investigating the safety of insect protein for farmed animals. Diets containing insect protein and their influence on animals need to be thoroughly analyzed. In the future, insect farming could become a novel branch of agriculture, and it could create new opportunities for Polish farmers who were affected by the African swine fever (ASF) virus. Insect farms could create new jobs, promote innovative business development, and increase food and feed production. Entomophagy is a new and controversial concept for Polish consumers, but in the future, it could offer a viable solution to feeding the world's growing population.

Keywords: edible insect, animal nutrition, proteins, entomophagy, agriculture, rural development, feed production

INTRODUCTION

The global population is currently estimated at 7.6 billion, and it is expected to reach 9 billion by 2050 (United Nations, 2012). Rapid population growth puts immense pressure on food producers, which is why special emphasis should be placed on sustainable food production, in particular the production of foods rich in high-quality protein (Mitsuhashi, 2010; Premalatha et al., 2011).

The increase of food production to a level that meets the needs of the rapidly growing human and animal population, while limiting the availability of new agricultural land, is currently impossible. At present, farmland occupies 30% of global land area, of which 70% is used for the production of animal feeds (Premalatha et al., 2011; van Huis, 2013). Intensive livestock production is one of the key drivers of change in the biosphere, and it significantly contributes to greenhouse gas emissions, global warming, soil degradation, air and water pollution, and the loss of biological diversity. Despite the above, animal breeding and farming is one of the most rapidly developing sectors of agriculture, and the demand for animal-based products continues to increase. These dynamic processes will also increase the demand for livestock feeds, and alternative sources of protein could help resolve these global challenges.

PRESENT SITUATION

The decision to fully ban the production, sale, and application of animal feeds derived from genetically modified (GM) plants should be preceded by long-term research aiming to identify alternative high-protein feedstuffs, characterized by similar quality and production cost to soybeans. Alternative protein sources include legumes grown on various types of soil, rapeseed meal, and dried distillers grains. The demand for oilseed meals has increased due to a surge in livestock production and the ban on the use of meat and bone meal in animal diets, introduced by many countries in 2000 after the bovine spongiform encephalopathy (BSE) crisis. In the last decade, the demand for high-protein raw materials in animal production increased by 39% to 350 million tons. To cater to this demand, the production of soybean meal increased by around 46%, from 171 million tons in 2010 to 249 million tons in 2020, and soybean is currently the prime source of feed protein with more than a 71% share in the global feed market. In the European Union (EU),¹ which is the world's second largest consumer of oilseed meals, their consumption increased by around 7% over the last decade. In the last two growing seasons, in particular in 2019/2020, the prices of oilseed meals clearly decreased below the long-term average. Between October 2019 and July 2020, the average price of soybean meal on the global market reached USD 369 per ton, and it was 11% lower than in the previous season and 15% lower than the long-term average. The prices of rapeseed meal, sunflower meal and fish meal followed a similar trend. In the 2019/2020 season, the average price of fish meal was USD 1,397 per ton, marking a 5% decrease from the previous season and a 9.5% decrease from the long-term average. The anticipated increase in the production and consumption of oilseed meals suggests that the prices of high-protein feed raw materials will remain low in the 2020/2021 season. In Poland, the leading sources of high-protein raw materials are oilseed (rapeseed) meal, fodder grain legumes, and animal meals (fish meal only since 2003). The production of rapeseed meal in Poland increased from 1.31 million tons in 2010 to 1.59 million tons in 2020. Poland has been a net importer of oilseed rape for four seasons, which implies that domestic production does not meet local demand. The production of soybean meal decreased from 12,000 tons in 2018 to 10,000 tons in 2019 (Dzwonkowski et al., 2015; Dzwonkowski, 2020). The selection of high-protein components for the production of animal feeds, in particular commercial feeds, is relatively limited in Poland.

A nutritionally balanced diet is essential for the growth, development and performance of animals. For these goals to be met, feed components should be characterized by high protein content, a balanced amino acid profile, high digestibility, and palatability. Animal feeds should be safe and free of antinutritional factors that compromise livestock health

(Barrows et al., 2008). Only selected ingredients of the highest quality should be applied in the formulation of animal diets to improve livestock productivity.

Fish meal is an excellent source of highly available protein. It is characterized by optimal proportions of essential amino acids and long-chain fatty acids, and it is highly abundant in vitamins and minerals (Olsen and Hasan, 2012). However, the growing demand for fish meal and the decline of fish stocks (resulting from, among others, the overexploitation of fisheries worldwide) have decreased the availability of fish meal and increased its prices.

The global feed market relies heavily on GM soybeans as the major source of protein in animal diets. At present, soybean production meets the global demand for feed protein. In 2014, GM soybeans occupied 82% of the global area under soybeans and 50% of the area under all GM crops. According to estimates, 93–95% of soybean meal on the market originates from GM crops; therefore, livestock production without the involvement of feeds containing GM soybeans is practically impossible, in particular in Europe and other highly developed countries (Dzwonkowski et al., 2015; Dzwonkowski, 2020). In the EU, soybean production is minimal due to an unfavorable climate for this crop, and soybean harvests rarely exceeded 1 million tons in recent years. Soybean meal is the most important meal in the EU, and it is largely imported. In recent years, Europe's soybean imports reached 13–14 million tons and accounted for 10% of global trade in this commodity (Dzwonkowski et al., 2015; Dzwonkowski, 2020). In Poland, the demand for feed raw materials is also largely met through imports. Poland imports around 2–3 million tons of soybean meal (1–1.5 million tons of pure 100% protein) each year.

Insects could be an alternative source of protein in the distant future. Both live insects and insect protein classified as processed animal protein (PAP) could be used in poultry nutrition. The total protein content of insect meal can be as high as 40–60%. The digestibility of amino acids in insect protein is also very high, at 91–95%. Insect larvae are an excellent source of energy relative to cereals and legumes. Edible insects also contain lipids with a favorable fatty acid profile (Siemianowska et al., 2013).

THE APPLICABILITY OF EDIBLE INSECTS IN POLAND

In Central Europe, various measures are being undertaken to search for alternative protein sources. The growing demand for animal feed will prompt producers to introduce innovative technologies and raw materials such as edible insects. Recent decades have witnessed an upsurge of interest in insects as potential food and feed sources. Research has demonstrated that insects can effectively supplement or replace conventional feed components, including soybean and fish meal.

Insect farming has enormous potential in feed production, and the insect-based food industry is developing rapidly in many countries around the world. According to the UN, edible insect consumption could reduce world hunger. Insect farming offers a sustainable and environmentally-friendly alternative to

¹Commission Regulation (EU) 2017/893 of 24 May 2017 amending Annexes, I, and IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council and Annexes, X, XIV, and XV to Commission Regulation (EU) No 142 / 2011 with reference to the provisions on processed animal protein (Journal of Laws L 138/92 dated May 25, 2017).

conventional food and feed production. One of the important aspects of the use of insects in the feed production sector is environmental and ecological considerations. Insect breeding requires minimal water consumption (Ooninx and de Boer, 2012). Insects do not need drinking water for their development, because they obtain it from fruits and vegetables. It is an incomparable cost relating to water consumption in pig and cattle farming, respectively. This aspect is of great importance in Poland, where water is becoming one of the most important factors in agricultural production (Mosiej, 2011; Orlińska-Wozniak et al., 2013). Insect farming is also characterized by low greenhouse gas emissions (Ooninx and de Boer, 2012). Therefore, insects can be considered the least polluting livestock (Ooninx and de Boer, 2012). In addition, insect breeding is considered a sustainable alternative to the production of poultry, cattle, and pigs. Insect breeding, despite the low impact on the natural environment, should have implemented biosecurity rules that will prevent the penetration of potential pests and pathogens into the breeding buildings and will protect the environment against potential escapes of insects (Józefiak et al., 2016; Fraqueza and Patarata, 2017; Doi et al., 2021). Insect farming can be a zero-waste production process because leftover food and frass constitute excellent natural fertilizer for gardening. Exuviae and chitin collected during the processing of insect larvae also constitute valuable raw materials, including for the pharmaceutical industry.

Insects (*Insecta*) are the largest group of organisms in the animal kingdom, and around 2 million insect species have been identified to date. Human attitudes toward insects vary considerably. Some people are repulsed by insects, whereas others perceive them as a valuable part of nature and human life. In nature, insects account for a significant part of the ecotone and play very important roles (New, 2009). Above all, insects are a source of food for other animals, such as fish, amphibians, reptiles, birds and primates, including humans (Boczek and Pruszyński, 2013; Raubenheimer and Rothman, 2013). Most insects provide key ecosystem services that generate benefits for humans and the environment (Yang and Gratton, 2014). Insects play a very important role in the carbon and nutrient cycle by decomposing dead organic matter (Heliölä et al., 2001). Nearly all agricultural ecosystems derive benefits from insects which suppress pest populations through biological control. In many cultures around the world, insects have been long used for medicinal purposes (Pemberton, 1999). Insects are applied in the production of vaccines and useful proteins (Cox, 2012). Larvae therapy is one of the most interesting medicinal uses of insects, where maggots are applied to infected wounds to speed up healing (Sherman and Wyle, 1996; Wang et al., 2010). Insects constitute also a very large group of diverse producers. The honey bee (*Apis mellifera*), silk moth (*Bombyx mori*) and Chinese oak tussar moth (*Atheraea pernyi*) supply valuable commodities such as honey and silk. Insects also play a key role as plant pollinators. The global economic value of pollination is estimated at USD 3 billion (Ingram et al., 1996; Losey and Vaughan, 1996).

Insects have been long regarded as an important source of protein in human and animal nutrition. Entomophagy, i.e., the consumption of insects, has attracted the interest of researchers

and ecologists as a potential solution to the unavoidable problem of feeding the world's growing population (van Huis, 2013; Verbeke, 2015). Insects are widely consumed in tropical countries, but they have not been incorporated into the human diet in the West (van Huis, 2013). More than 2000 edible insect species have been identified to date (Jongema, 2021).

Societies of European Union countries have different approaches to entomophagy. The use of edible insects in the production of feed and food is still a controversial topic to Polish society. Currently, there is lack of broader information on the acceptance of entomophagy insect farming in Poland. In Poland, insects are mostly consumed sporadically and are regarded as an exotic curiosity. A single survey was conducted among Poles by Zielińska et al. (2020). They stated, that Polish consumers have limited knowledge of entomophagy, and the main barriers are neophobia and unawareness (Zielińska et al., 2020). Processed insect products can increase consumers' tendency to buy insect-based products (Zielińska et al., 2020). Among the surveyed group of consumers, 15.51% of the respondents tried insects and about 60% rated their taste as good or very good (Zielińska et al., 2020). In Poland, higher awareness of entomophagy is required to accept insects as food besides the willingness to try (Zielińska et al., 2020). Research conducted in the neighboring Czech Republic shows that 37.8% of respondents have tried insects, of which 11.8% eat them regularly (Kulma et al., 2020). From a socio-demographic point of view, age and gender had a significant influence on the responses; younger people and men reported more positive (Kulma et al., 2020). It is very important that 77.7% of respondents say that they would not mind eating meat products from livestock that were fed to insects (Kulma et al., 2020). Zielińska et al. (2020) suggests that the future of insect consumption depends on the sensory properties of insect-based products, therefore the food industry should focus on processed foods with insect-based food ingredients to make them known to consumers. In Polish society, it is necessary to develop an awareness strategy that edible insects are healthy and safe in human and animal nutrition. Marketing strategies should be developed for insect products as well as products from animals fed with insects. Social education also seems necessary, in particular aimed at farmers and future consumers. Education for farmers would help them realize that insects are a good alternative to conventional livestock. However, there is a lack of information on the acceptance of insects among farmers or feed producers in Poland. Lectures and workshops for children may be of particular importance, as getting to know entomophagy from an early age may allow for greater acceptance of this phenomenon in the future. Despite the above, insects have the potential to contribute to feeding the globally expanding human population.

Insect protein can be used in the production of fish feed in the EU, and it offers a viable alternative to feeding other livestock species in the future. The edible insect market continues to grow, and global output is expected to increase from 2000 tons in 2018 to around 200,000 tons in 2020 and 1 200 million tons in 2025 (International Platform of Insects for Food Feed (IPIFF), 2018). Insects are a natural component of animal diets, and they are a rich source of highly digestible protein in animal nutrition. Some insects contain bioactive and

immunostimulatory ingredients such as lauric acid, antimicrobial peptides and chitin (Dossey, 2010). Several European producers are offering pet food containing insects, and this trend is likely to spread in the coming years. At present, insect protein is classified as PAP, and it cannot be fed to farm animals (poultry, pigs). In the light of the existing legal regulations, PAP can be applied only in aquaculture. Approximately 78% of insect producers in the EU regard insect-based feed as a promising alternative in poultry farming and animal production. Regulation (EC) 2017/893 permitted the use of insect-based proteins in aquaculture, and legislative efforts aiming to introduce insect protein in poultry and pig nutrition are currently under way.

Currently, in Poland, the breeding of insects, as well as the keeping of other farm animals, is controlled by the Veterinary Inspection and the Sanitary Inspection in the case of being intended for human nutrition. Despite the fact that there are numerous legal regulations regarding the breeding of insects and insect-derived products all over the world, Poland still does not have national legal regulations regarding this subject. Therefore, the relevant regulations of the European Union apply in the country. European Union regulations mainly concern the hygiene of foodstuffs, with particular emphasis on feed and food of animal origin.

Protein-rich insects are a natural ingredient of feeds in organic fish and poultry farms. Insect larvae can be fed a wide range of by-products, which contributes to the recycling of food and agricultural wastes. Biological processing of organic waste is a very important concept because insect-based feeds would not only decrease the protein deficit in Poland, but would also significantly reduce the volume of waste produced in agriculture and the food processing industry. Insect larvae could decrease the volume of organic waste by 60%. Research has demonstrated that insect protein supplementing conventional vegetable sources in animal diets would also increase the area of agricultural land for the production of foods that are directly consumed by humans. Therefore, edible insect farming has a potential to increase global food safety without high environmental impact (Doi et al., 2021).

The benefits resulting from the inclusion of edible insects in animal diets have to be carefully analyzed in the search for sustainable and long-term solutions in livestock nutrition. Decisions concerning the safe introduction of insect protein to the nutritional regime of animals have to be based on sound research. In Poland, such efforts are being made under a research project entitled “Development of a strategy for the use of insects as alternative protein sources in animal nutrition and the promotion of insect farming in the Republic of Poland.” The project is being carried out by a research consortium comprising the Ministry of Agriculture and Rural Development, University of Warmia and Mazury in Olsztyn, and the National Veterinary Research Institute in Puławy. The aim of the project is to develop a strategy for the production of insect protein based on the results of a research study which identified insect species that can be farmed under Polish conditions. The strategy will also define the optimal parameters of insect breeding and production technology, as well as the requirements for the storage and application of insects and insect-based products in animal nutrition. Currently, there are no major companies

involved in the large-scale production of insects in Poland, except the company “HiProMine,” which is a pioneer and leader in insect breeding and the development of breeding techniques in the country. The “Hipromine” carries out many development projects, such as “Development and verification of innovative methods of slaughter, sterilization, drying, and fat separation from *Hermetia illucens* larvae, as a way to reduce the production costs of functional feed materials with increased quality parameters in real conditions” or “innovative technology of industrial insect reproduction.” The “Tenebria” company is currently implementing the “Automatic mealworm rearing system together with the development of feeding technology.” The remaining existing entities are characterized by extensive or small-lot production, based on significant labor inputs due to the lack of hardware infrastructure. The current level of development of insect production in Poland is at an early stage and the creation of a profitable mass production of insects requires a significant costs reduction, for example through the automation of breeding. Therefore, on the Polish market there are significant technical and organizational limitations in the production of insects, which is the most characteristic of this sector. Contrary to the Polish market, there are large entities in the world that implement industrial production of insects (e.g., Ynsecta, Haocheng Mealworm). However, they function under completely different technological conditions. In Poland, there are also minor scientific projects concerning the use of insects in the processing of waste, e.g., polystyrene.

The selection of optimal insect species for the production of animal feed poses a considerable challenge. Thousands of insect species are consumed around the world, but only some of them are suitable for large-scale farming. The choice was influenced by numerous factors, including environmental and climatic conditions, nutritional requirements, nutritional value, and the types of organic waste that can be applied in insect farms. Several insect species were considered during the project. The insects that are classified as livestock in the territory of the European Union were analyzed, including: black soldier fly (*H. illucens*), house fly (*Musca domestica*), lesser mealworm (*Alphitobius diaperinus*), yellow mealworm (*Tenebrio molitor*), tropical house cricket (*Gryllobates sigillatus*), house cricket (*Acheta domestica*), and Jamaican field cricket (*Gryllus assimilis*). The selection also included insects consumed in other parts of the world, including: cockroaches (Blattodeae), superworm (*Zophobas morio*), green rosechafer (*Cetonia aurata*), green bottle fly (*Lucilia sericata*), greater wax moth (*Galleria mellonella*), silkworm (*B. mori*), mediterranean field cricket (*Gryllus bimaculatus*), and locusts (Acrididae). Two optimal species were ultimately selected.

Based on a review of the literature, the black soldier fly (*H. illucens*) was regarded as the best candidate for the production of animal feed, whereas the mealworm beetle (*T. molitor*) was selected as the optimal species for the production of both feed and food. The relevant literature was quite extensive because considerable research has been done on the applicability of both species for industrial farming around the world. Both of these insects have biological aspects that affect the ease of breeding and future economic benefits. Selected species intended

for mass production in Poland have positive features such as: rapid growth; short development cycle; high survival of juvenile stages; high level of egg laying; high daily growth potential of biomass; high feed conversion rate; ability to live in high densities and low susceptibility to infectious diseases (Li et al., 1998, 2013; Lambkin, 2001; Wu, 2009; Wu et al., 2009; Nguyen et al., 2013, 2015; Kim et al., 2015; Adámková et al., 2017; Grau et al., 2017; Müller et al., 2017; Wang and Shelomi, 2017; Chia et al., 2018). Moreover, these insects have low requirements for the area occupied for breeding purposes and easy to maintain thermal and humidity conditions (Wu, 2009; Wu et al., 2009; Wang and Shelomi, 2017; Chia et al., 2018).

At present, the global insect market relies largely on the black soldier fly and mealworms, and the reported results are satisfactory. After the introduction of Regulation 2017/893, which allows the use of insect protein in the nutrition of companion animals and aquaculture, these substrates may be implemented in the nutrition of other animals in the future. In the literature, there are many applications of insects as a potential feed ingredient for farm animals. Research showed that insects can be used in feeding laying hens (Marono et al., 2017; Bovera et al., 2018; Ruhnke et al., 2018; Secci et al., 2018). Replacing soybean with insect meal did not affect the productive performance of laying hens (Marono et al., 2017) and the quality of the eggs (Secci et al., 2018). The positive attitude of consumers to the eggs from insect-fed hens is also important (Spartano and Grasso, 2021). Insects can also be used to feed broilers (Ramos-Elorduy et al., 2002; De Marco et al., 2015; Khan et al., 2018; Altmann et al., 2020). It was shown that the insect-based diet had a positive effect on meat quality and did not affect animal mortality (Khan et al., 2018). Insects also decreased the feed conversion ratio in broilers (Bovera et al., 2016). Insect products appear to be a good alternative to partially replacing traditional protein-rich ingredients in pig diets (Veldkamp and Vernooij, in press). Insect supplementation of in weaning pigs' diet improves growth performance and nutrient digestibility (Jin et al., 2016). Insects also do not significantly modulate pigs metabolism (Meyer et al., 2020). Insects are also a part of the diet for farmed fish (Nogales-Mérida et al., 2019). In breeding Atlantic salmon, no negative effects were found after the introduction of insects into the diet. Insects in fish may also have a probiotic effect, due to the presence of chitin and antimicrobial peptides (Nogales-Mérida et al., 2019). Research suggests that insect-fed fish acceptance is very high among consumers (Mancuso et al., 2016). However, the disadvantage of using insects in fish nutrition may be the increase in production costs (Arru et al., 2019). A detailed description of the possibility of using insects as substitutes in the production of feed for many animal species was presented by Makkar et al. (2014). Live and processed insects can be utilized to feed animals. The development of insects processing for food and feed purposes enable to isolate pure protein or extract fat. Insect meal shows great potential in animal nutrition (Sánchez-Muros et al., 2014; Sogari et al., 2019).

Both *H. illucens* and *T. molitor* meet the criteria for the most suitable insect species, and can be reared on organic waste to transform low-value agricultural waste and by-products into high-quality protein. Larvae feeding on fruit, vegetables and

other plant substances, as well as animal tissues and manure bioconvert these products into protein-rich biomass (Sheppard et al., 1994). The selected insect species have a short breeding cycle, and the high number of eggs laid by females supports rapid insect production. For example, *T. molitor* females lay 400–500 eggs that hatch after 7 days, and the emerged larvae require 45–60 days to reach the pupal stage (Manojlovic, 1987; Stebnicka, 1991; Broekhoven et al., 2015). Insects in various stages of development can be used in the production of animal feed (Hale, 1973; St-Hilaire et al., 2007). Black soldier fly pupae contain 35–37% protein and 35% fat, and *T. molitor* larvae are one of the most abundant sources of protein (47.76–53.13%) and lipids (27.25–38.26%; Siemianowska et al., 2013; Bovera et al., 2015; Broekhoven et al., 2015). Insects are also rich in biogenic elements, niacin, pyridoxine, riboflavin, folic acid and vitamin B12 (Rumpold and Schlüter, 2013; Cortes Ortiz et al., 2016). Complete diets containing insect protein were found to promote the growth of chickens, pigs and many species of farmed fish (Newton et al., 1997; St-Hilaire et al., 2007; Bovera et al., 2015). A study of animal diets containing insect meal derived from the analyzed species (replacing 20–30% of soybean protein) revealed satisfactory body weight gains, high meat quality and digestibility (Bovera et al., 2015). A comparison of these insect species with conventional meat revealed that mealworms have a much higher nutritional value than beef and chicken meat (Nowak et al., 2016; Payne et al., 2016).

Minor requirements as to the area needed for insect breeding generate lower initial investment costs. In contrast to conventional livestock farming, insects can be bred taking into account the entire cubature of the building. The solutions used in breeding both of these insects reduce the costs of breeding related to infrastructure and animal service. Land use is increasingly important in agricultural production in Poland (Wysokinski and Dziwulski, 2013). Thanks to three-dimensional farming, extensive investment/agricultural areas are not needed to set up an insect farm. Initial costs are lower, also due to the feed used in breeding these insects, e.g., second-class plant foods or unsold food products. Insects can also minimize the cost of disposing of agricultural or food by-products through bioconversion of organic matter (Salomone et al., 2017; Fowles and Nansen, 2020). This phenomenon can contribute to the natural recycling of nutrients and is environmentally sustainable (Salomone et al., 2017). In Poland, currently the largest costs of insect production are related to the salaries of employees. In the future, however, this phenomenon may be minimized by the developing automation of insect breeding. A significant cost that investors must bear at the beginning of production is also the adaptation of the rooms in order to obtain optimal zoohygienic conditions.

Under the present conditions, a complete replacement of plant protein substrates, especially soybean, by insect protein seems unlikely in Poland. This is due to the price of insect meal and low availability on the market. Partial replacement of legumes seems to be the best solution for the implementation of insects in animal nutrition. The coefficients of replacement of plant components of feed by the insect component can be up to 50% without negative effects on the health and utility value of some animal species

(Makkar et al., 2014). The support of feed manufacturers may be of great importance in the utilization of edible insects. In Poland, this sector is dominated by large concerns that cover over 90% of the demand. With regard to the insect breeding in Poland, it is necessary to identify factors that hinder and enable the use of insect PAP in animal nutrition. It is also necessary to define the interest and opinions of feed producers and farmers regarding the possibility of using insects in their activities. The largest feed producers are likely to be among the most important institutions in introducing this innovation. Information obtained from feed producers may be important in the design of future implementations.

SUMMARY

The influence of insect protein on animals has to be evaluated, and insect-containing diets have to be formulated to assess the feasibility of PAP production in Poland. In the authors' opinion, insect farming will create new opportunities for Polish farmers and feed mills. In Poland, insect protein can be produced in large-scale industrial rearing facilities as well as in small-scale farms which are an integral part of Polish agriculture. In the future, insect farming will create new jobs, stimulate entrepreneurship, and increase food and feed production. The production of edible insects for livestock feeds could also provide an alternative source of income for pig farmers in north-eastern Poland, in particular in the voivodeships of Podlasie, Masovia, and Lublin, which are periodically affected by the African swine flu (ASF)² virus. The number of ASF outbreaks in pig farms

²Główny Inspektorat Weterynaryjny, ASF w Polsce - Mapy, Obszary Objęte Restrykcjami, Ogniska, Przypadki. <https://www.wetgiw.gov.pl/nadzor-weterynaryjny/asf-w-Polsce>.

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reached 213 in 2018, 48 in 2019, and 103 in 2020 (<https://www.wetgiw.gov.pl/nadzor-weterynaryjny/asf-w-Polsce>). More than 2,000 infected pig herds were culled in Polish farms. Farmers who suffered economic losses due to ASF could switch to edible insect farming by harnessing on their productive potential and local resources. The use of edible insects in the production of feed and food is still a controversial topic in Poland. However, the existing challenges could be overcome by disseminating knowledge on the nutritional value of edible insects. Insect farming has considerable potential to reduce undernutrition and contribute to food safety.

AUTHOR CONTRIBUTIONS

RG: conceptualization, data curation, formal analysis, investigation, software, writing—original draft, and writing—review and editing. ŁZ: funding acquisition, supervision, and writing—review and editing. MZ and JG: formal analysis and project administration. TB: project administration, funding acquisition, investigation, supervision, writing—original draft, and writing—review and editing. All authors have read and agreed to the published version of the manuscript.

FUNDING

This article was developed as a part of a research project entitled Development of a strategy for the use of insects as alternative protein sources in animal nutrition and the promotion of insect farming in the Republic of Poland, co-financed by the National Center for Research and Development under the GOSPOSTRATEG program. Agreement No. GOSPOSTRATEG1/385141/16/NCBR/2018. Project value: PLN 5,214,500. Amount of funding: PLN 4,983,700.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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