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INSECTS AS FOOD – OPPORTUNITIES AND CONSTRAINTS®

Owady jako żywność – możliwości i ograniczenia®

Key words: novel food, insects, source of protein, plant protein, opportunities, constraints.

The interest of the food and feed industry in animal protein alternatives is increasing worldwide. Among the most commonly used alternatives are plant proteins, but interest in insect proteins as well as the use of whole insects in food is still growing. The aim of this study was to analyze the possibilities of using edible insects in food as well as the limitations associated with their use in food products. The production process, safety issues, consumer opinion, popularity of insects in different corners of the world, nutritional value, as well as the sustainability of insect production as a protein source compared to conventional production are discussed. The opportunities as well as the limitations in the use of insects in food were highlighted. Many examples of the use of insects in equal food products were also given. Despite the emerging economic and environmental opportunities associated with the use of edible insects as a protein alternative in the future, there are still some limitations and restrictions on the industrialization of edible insects in food products, from the breeding, processing and promotion of edible insects to their acceptance among consumers.

Słowa kluczowe: nowa żywność, owady, źródło białka, białko roślinne, możliwości, ograniczenia.

Zainteresowanie przemysłu spożywczego jak i paszowego alternatywami białka zwierzęcego jest coraz większe na świecie. Wśród najczęściej wykorzystywanych alternatyw są biała roślinne, niemniej jednak zainteresowanie białkiem owadzim jak również wykorzystaniem całych owadów w żywności nadal rośnie. Celem artykułu była analiza możliwości wykorzystania jadalnych owadów w żywności jak również ograniczeń związanych z ich użyciem w produktach spożywczych. Omówiono proces produkcji, kwestie dotyczące bezpieczeństwa, opinii konsumenckiej, popularności owadów w różnych zakątkach świata, wartości odżywczej, jak również zrównoważonej produkcji owadów jako źródła białka w porównaniu do produkcji konwencjonalnej. Zwrócono uwagę na możliwości jak i ograniczenia w zastosowaniu owadów w żywności. Podano również wiele przykładów wykorzystania owadów w różnych produktach spożywczych. Pomimo pojawiających się możliwości ekonomicznych i środowiskowych związanych z wykorzystaniem jadalnych owadów jako alternatywy dla białka w przyszłości, nadal istnieją pewne ograniczenia i restrykcje w uprzemysłowieniu jadalnych owadów w produktach spożywczych, od hodowli, przetwarzania i promowania jadalnych owadów po ich akceptację wśród konsumentów.

INTRODUCTION

Population development continues to increase, as well as the impact of agriculture in meeting human food on climate change, has led to many studies being conducted to find alternative proteins that are still of high quality and affordable, but are more environmentally friendly. Beef is one of the most consumed protein sources, but unfortunately it is the food that requires the most environmental inputs and has the greatest impact compared to other protein sources [87]. On the other hand, vegetable protein groups, such as legumes, require fewer environmental inputs than beef, but production on an industrial scale requires fuel, fertilizers and pesticides, which are close to beef and chicken [87]. Thus, it is necessary to have other alternative protein sources to fill the gap.

Protein is one of the most important nutrients in life. Besides water, protein is the most abundant compound in the human body. Protein plays a role in the growth and maintenance of body tissues, especially in the formation of structure, function, and regulation of organ tissues in the body so that it needs to be regenerated continuously [89]. In addition, proteins also play

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a role in the formation of hormones and antibodies, storage and transportation of molecules, as well as enzymes that play a role in biochemical reactions in the body [89]. Insufficient protein intake can lead to malnutrition [13].

Meeting protein needs can be met through the consumption of high-protein foods. It can be in the whole form (raw, cooked or processed) or designated food products that contain either protein from animal or plant sources [10]. Animal protein majorly can be obtained from dairy, meat, seafood and eggs [10]. While vegetable protein can be obtained from plants such as cereal, legumes, nuts, seeds and microalgae [10]. The quality of animal and vegetable protein varies, depending on the content of essential amino acids that are important in physiological requirements and nitrogen balance and bioavailability in the human body [15; 87].

Animal protein in terms of its essential amino acid content has a greater value when compared to vegetable protein. In addition, protein contained from animal sources also brings other nutrients needed by the body such as fatty acids and certain micronutrients, namely zinc and vitamin B12 [15]. Vegetable proteins such as nuts are high in unsaturated fatty acids in the form of MUFA (monosaturated fatty acid) and PUFA (polysaturated fatty acid), as well as protein which is quite high when compared to animal protein, but the anti-nutritional content found in nuts can reduce its bioavailability in the body and low consumption of animal protein such as vegetarian food which consumes more vegetable protein, causing a lack of intake of micronutrients zinc and vitamin B12 [85]. Thus, it is recommended to consume a balanced diet of plant and animal foods to meet each other's body needs.

OPPORTUNITIES AND CONSTRAINTS

Edible insects in the past and today

Insects are arthropod species with a chitinous exoskeleton, a three-part body (head, thorax, and abdomen), jointed legs, compound eyes, and two antennae [57]. Insects are the only flying invertebrates that are cold-blooded and undergo metamorphosis in order to adjust to seasonal changes, breed swiftly, and have vast populations [96]. Their respiratory systems are resistant to air and vacuum pressure, as well as high altitude flying and radiation, and they rarely require parental care [96]. Insects may be found in almost any habitat, with the exception of the ocean, where just a few species exist [96].

Insects are currently one of the foodstuffs whose potential has begun to be explored to meet human food needs. More than 2000 insect species have been consumed worldwide [98] (Table 1). Eating insects as a food usually come with the term entomophagy. The name "entomophagy" is derived from the Greek words "*entomos*" (insects) and "*phagein*" (to eat), and the combination of both terms implies "insect eating" [79]. There are differences in the eating habits of edible insects in various countries, much influenced by the culture of food consumption, religion and its availability in various regions [40]. For some region like in the western culture, eating whole insects is still uncommon thing to do [78], but for other regions, it is still a preference for their delightful taste, event collecting insects is a part of enjoyable activities [70].

Table 1. Common insect species consumed worldwide and harvested nowadays

Tabela 1. Popularne gatunki owadów spożywane na świecie i hodowane współcześnie

Common consumed insect	Common harvested insects
Silkworm (*Bombyx mori*)	Grasshoppers (*Melanoplus foedus, Acrida turrita* (L.), etc)
Catterpillars (Cirina forda)	Silkworm (*Bombyx mori*)
Palm Weevil (*Rhynchophorus ferrugineus* (Oliv.), *Rhynchophorus phoenicis* (Fabr.), etc)	House Cricket (*Acheta domesticus*)
Ants (*Oecophylla sp.*, *Camponotus japonicus* Mayr, etc)	Mealworms (*Tenebrio molitor*)
Grasshoppers (*Melanoplus foedus, Acrida turrita* (L.), etc)	Locust (*Locusta migratoria*)
Locust (*Locusta migratoria*)	Termites (*Macrotermes nigeriensis*)
Beetles (*Onitis spp.,Copris spp.,Heliocopris spp.*)	Cicada (*Orientopsaltria spp., Dundubia intermerata Walker, Cicadidra spp.*)
Crickets (*Acheta domesticus, Gryllus assimilis*)	Dragonfly (Order Odonata)

Source: Own elaboration based on [27, 39, 48]

Źródło: Opracowanie własne na podstawie [27, 39, 48]

Insects as food

Despite the fact that 80 percent of the world's population is accustomed to eating insects, the consumption of edible insects is yet unexplored and considered inappropriate by many civilizations. Insects are a novel meal, and knowledge on the safety and nutritional value of edible insects is limited, particularly given their wide variety [86]. Many studies state the potential of insects as a future food solution due to their affordability, quality and sustainability. The development of edible insects is also expected to solve several problems at once both in terms of economy, food, nutrition and the environment. Currently, consumption of edible insects is still mostly dominated in western areas with wider and varied food acceptance [68]. In Australia, research and a long-term road map for the development of these edible insects have also been established to explore the potential of local edible insects [77]. While in Asia itself, several countries have made edible insects as one of the commonly consumed food ingredients such as in Thailand, Vietnam and Myanmar [40; 39].

Eating insects whole or just with visible body parts might be hard for people raised in Western society. People in environments where insects have not been ingested for a long time prefer to incorporate insects into meals in such a manner that they are unrecognizable [78]. These considerations imply that ‚hiding' insects in products will make them more approachable in the future. In practice, dried insects can be crushed or pulverized, while raw or cooked insects can be ground or mashed, resulting in an unidentifiable insect shape [67].

Table 2. Insects as a food - opportunities and constraints

Tabela 2. Owady jako żywność - możliwości i ograniczenia

Opportunities	Constraints
1. Insects are frequently consumed as a delicacy, and insects are not inferior to other protein sources such as fish, poultry, and cattle. 2. Insects are clean, pleasant, and nutritious. 3. People who have eaten insects before have a significantly more positive attitude toward entomophagy than people who have not, and are more likely to eat them again. 4. Insects in the form of powder can be a good approach to develop many kinds of insect-based products that is more acceptable to the consumers. 5. Edible insects are potential to be developed by the food industry as food and feed enrichment and fortification materials. 6. Insects can be a solution to several problems at once (nutrition, food, economy and environment) due to their quality, affordability and sustainability. 7. „Green consumer", a fitness and health oriented consumer may be the main target for insect-based products due to his concern for health 8. Insects can be promoted as something unique and exciting for the consumers. 9. Insects can be reared and harvested throughout the year, almost all parts of their body can be consumed, have high fertility and growth rates, and are more efficient in converting the substrate they consume into body mass. 10. Insects have a high feed conversion efficiency value. 11. Insects have great potential in solving environmental problems. They are one of the solutions to the growing issue of climate change. 12. The small farm model has the ability to grow a greater variety of insects, reduce genetic diversity loss, and reduce the likelihood of an insect illness spreading across a colony. 13. Edible insects can provide protein (20-70% of raw protein), amino acids (30-60%), fat (10-50%) and minerals and vitamins. The minerals and vitamins contained include phosphorus, sodium, iron, copper, zinc, manganese, potassium, vitamins B1 and B2 and niacin. 14. Crickets show superior nutritional value with a higher content of protein, minerals (iron, zinc and magnesium) and fat with less SFA, but higher PUFA content. 15. Insects can provide equivalent nutrients, not only compared to meat, but also from other food sources such as shellfish, nuts, vegetables and even fruit.	1. Insects in Europe are synonymous with discomfort and are associated with dirt, fear of contamination and disease, as well as psychological and biased perceptions of taste, smell and color. 2. A common belief is that insects are unclean, unsanitary and/or disease carriers. 3. Western aversion to entomophagy contributes to the widespread view that entomophagy in developing countries is motivated by hunger and is solely a survival mechanism 4. Several challenges need to be considered in the safety of food based on edible insects, namely the content of anti-nutritional compounds, allergens, biological and other chemical hazards. 5. Edible insect producers are expected to be able to comply with local food product regulations. 6. Like other food products, edible insects must be kept under hygienic conditions and constantly inspected for nutritional content and taste to maintain their quality. 7. The nutritional content of edible insects will be influenced by several factors, including: the type of species and its processing, growth stage, sex, and external factors such as weather, food, and the edible insect's habitat. 8. As interest in raising insects for commercial purposes increases, significant steps will need to be taken to ensure that the supply of insects does not harm the environment. 9. Harvesting of insects under natural conditions will soon be insufficient to meet demand. Processing will have to be automated. 10. Harvesting insects in the wild is the most common method of collecting insects in most nations. In some cases, the cost of insects can be much higher than the cost of meat. 11. When evaluating insect breeding, it is important to identify aspects that affect the substrates or feeds used, as well as the conditions in which the insects are placed. 12. Breeding insects should have access to high quality nutrients, be allowed to express natural behavior, be free from discomfort, pain, injury and disease during the breeding process, and be housed in a breeding environment that is as close to their natural environment as possible to maximize animal welfare. Killing methods that guarantee a quick death are also recommended. 13. In the case of insects, more research is needed to assess their ability to transmit diseases. 14. The most effective methods to ensure the survival and reproduction of insects should be studied and developed.

Source: Own elaboration based on [6, 8, 12, 19, 27, 32, 33, 34, 38, 39, 40, 43, 52, 67, 73, 78, 79, 82, 96, 97, 99, 100, 102]

Źródło: Opracowanie własne na podstawie [6, 8, 12, 19, 27, 32, 33, 34, 38, 39, 40, 43, 52, 67, 73, 78, 79, 82, 96, 97, 99, 100, 102]

Table 2 and the further part of the article present the most important points indicating the opportunities but also the constraints arising from the use of edible insects as food.

Popularity of insects in different corners of the world

Currently, the consumption of edible insects that are still not common is caused by various things. The meta-analysis conducted by Wassmann et al. [102] regarding the willingness to consume (Willingness to Consume/WTC) of insects, showed a correlation between "fear of food change" (food neophobia), "disgust", and "expectations of discomfort by eating insects" and WTC. However, this can be overcome in the long term by introducing insects as food, such as by developing education on the concept of eating insects and providing direct experience of "eating insects" in the community [102]. Research by Suthar et al. [90] shows projections of edible insects in the future with various scenarios that may occur both as food and feed. So that food products based on edible insects will be very potential to be developed in the future.

ASIA

Entomophagy is a common practice in several Asian nations. Some nations in the Asia Pacific area have access to information on edible insects, however it is scattered [106]. There is relatively little published material for peninsular Malaysia, Myanmar, Nepal, Pakistan, many Pacific islands, and Taiwan, while Australia, Indonesia, Papua New Guinea, the Philippines, and Vietnam still have knowledge gaps. In nations with a long history of this practice, diminishing insect eating has been recorded as diets have transitioned to a more westernized pattern, followed by a population movement to urban regions [97]. However, there is an exception to this pattern in Southeast Asia [107].

In Malaysia, although there is no specific regulation for insect used, the laws apply to food safety and quality including the use of insects [55]. In China, although the Ministry of Health has allowed silkworm pupae as food in 2014, the food safety standards for edible frozen fresh silkworm pupae available in local area of Guangxi Zhuang Autonomous Region (DBS45/030 – 2016) [54]. Meanwhile in Thailand, the authority about edible insects falls under Food and Drug Administration, Ministry of Public Health with the regulation Food Act B.E.2522 [29]. In Republic of Korea, in order to support the insect farmer and national economy, some legal measurement has been established [84]. The same goes to Thailand, where Thai National Bureau of Agricultural Commodity and Food Standards (ACFS) from the Ministry of Agriculture made a guideline to cricket farming [66] and rearing silkworm for silk production [65].

EUROPE

Except for those who have allergic responses, humans, particularly those from North America and Europe, can consume insects if they do not know what they are eating [78]. In Western societies, where protein is still primarily derived from domesticated animals (cow, pig, chicken, etc.) and proteinaceous seed (pulses), insects are almost related with discomfort: mosquitoes and flies invade homes, the former leaving behind unwanted bites; termites destroy wood possessions; and some insects end up in meals, triggering the disgust factor [96]. A mechanical vector, such as a house fly, can take up an infectious agent on the exterior of its body and transport it to food [96]. These are some of the reasons why the European Society refuses to eat edible insects, and deliberate human entomophagy is uncommon in westernized societies [105]. With such a background, it is not surprising that insects in Europe relate to dirt, fear of contamination and disease, as well as a psychological and biased perception of taste, odor, and color [12]. With proof that insects are clean, pleasant, and nutritious [32], there are potential to investigate the cultivation of human-grade insects for human consumption and to expand the prospect of substituting animal products with insects.

The Western dislike for entomophagy contributes to the widespread idea that entomophagy in the developing world is motivated by famine and is purely a survival mechanism [96]. This is not the truth, since insects are frequently consumed as a delicacy, and insects are not inferior to other protein sources such as fish, poultry, and cattle. Furthermore, due to the ecological benefits of insects over other animal protein sources, shifting from animal products to consuming insects might have significantly impact animal product consumption in nations [86]. There are already hints that customer attitudes in developed countries such as the United States and the United Kingdom are shifting [45], and the barrier to include insect-derived components in other products, such as powder [7], may not be as high. Some studies on accepting entomophagy conducted in European countries such as the Netherlands [56] have found that people who have eaten insects before have a significantly more positive attitude toward entomophagy than people who have not, and are more likely to eat them again. As a result, it appears critical to encourage individuals to take „the first step" and become acquainted with eating insects [78]. As a result, giving informative education to the customers on entomophagy should be performed [56].

All insect-based product has been authorized as novel food in 2018 and fall under novel food regulation EU 2015/2283 [24]. In the European Union, reared insects including in "farmed animals" [22] and it is regulated under animal livestock health and biosecurity measures on transmissible diseases [23]. To prevent issues related to spongiform encephalopathies, processed animal proteins (blood products, gelatin, collagen, hydrolyzed proteins of animal origin and derived from ruminants) cannot be used as a substrate for insects [21]. There are some exceptions, such as processed animal protein products from seven insect species that can be used as part of the formulation for aquaculture feed and pet food in the European Union, they are *Hermetia illucens, Musca domestica, Tenebrio molitor, Alphitobius diaperinus, Acheta domesticus, Gryllodes sigillatus* and *Gryllus assimilis*) [25].

AMERICA

It is noteworthy to mention that pre-Western cultures has been practice entomophagy [88]. Around 90 species of edible insects have been consumed in North America [48]. Some of them are Coleoptera (beetles, weevils, borer), Diptera (shore fly, botfly larvae), Hemiptera (water bug, honey bee, cicada), Orthoptera (locust, mormon cricket), Hymenoptera (ants, wasp, hornet), Lepidoptera (butterflies, moths) [88]. Certain insects such as locust, wild honey, cricket, katydid and grasshopper are being mentioned in bible and in Sunnah based on the beliefs spread in America [88]. Guine et al. [37] also recorded that tarantula spiders being consumed in Latin America (Cambodia and Venezuela). In South America, Termites are more popular to be consumed uncooked like a snacks [37]. The past practices of entomophagy are better documented in western part of North America than other parts (eastern and northern areas) [88]. There is an assumption that eating insects related to negative perspective and starving condition [88]. Although it is currently still uncommon to use insects as food in most western regions such as North America, but insect-based food such as cricket powder or insects offered by a restaurant are starting to become well known for the sustainable reason of offering food rich in cheap proteins [88].

The legal framework for food uses of edible insects and its derivatives products in America fall within the oversight of the United States of America Food and Drug Administration (FDA) informal policy the same goes to other food [27]. If they are added to processed food, e.g. as an ingredient or additives, it falls under Generally Recognition as Safety (GRAS).

AUSTRALIA

Witchetty grubs, Honey ants, and Bogong moths (*Endoxyla leucomochla*, *Myrmecocystus mexicanus,* and *Agrotis infusa*) are among the insects that are included in the traditional diet of indigenous Australians (also known as the 'bush tucker' diet) [72], but the consumption of insects in Australia is otherwise considered to be a novelty. Perceptions of insects as pests [96], dirty, unpleasant, and hazardous [58], have a detrimental impact on the adoption of insects as a source of nutrition. Customers' resistance to eating insects has related to sentiments of disgust [12; 41; 53; 101], which are frequently associated with beliefs of risk, such as insects being unclean, unsanitary, and/or disease carriers [97].

Currently, Ponce-Reyes and Lessard [77] has made a roadmap for strategic growth of edible insects in emerging Australian market. For the regulation, according to the Food Standards Australia New Zealand (FSANZ) Advisory Committee on Novel Foods (ACNF), some edible insect species (*Z. morio, T. molitor* and *A. domestica*) are considered non-traditional food, but not novel food [27; 30]. This means that they need to follow the regular Food Standards Code [31].

AFRICA

The African diets consist of a vast variety of wild foods, which include edible insects. In Africa, there are about 1,500 edible insect species. As the prices of beef, poultry, and fish continue to climb throughout the world, a fantastic opportunity for insects to supply mankind's and livestock's animal protein demands now and, in the future, has surfaced [78]. In Africa, the demand for edible insects is increasing, mostly because animal protein is becoming more expensive and scarcer [78]. The desire for healthier alternatives and insects has increased, and this has enormous potential in animal feed production. A wide range of insects are consumed [78].

In tropical African countries, the majority of bug species are harvested from the wild, with the majority of harvesting carried out by women. As an example, in the wild, palm beetle grubs are gathered from raffia or palm stems, and their availability is related to seasonal fluctuations. In traditional settings, the method used to capture insects from the wild is heavily influenced by the behavior of the insects. Palm weevils can be attracted to artificially created breeding grounds, and the sound made by cricket species can be used to detect the species in question. Some nocturnal fliers, such as termites and grasshoppers, can be enticed into traps using artificial illumination. In order to control some insects found in trees or bushes, it is possible to apply glue to the top of a branch, twig, stick, or stem [39].

While various insect species are consumed in many African countries, there appears to be a lack of specific regulatory frameworks for using insects as food [36]. There are some exceptions, such as mopane caterpillars (*Imbrasia belina*) are considered edible according to Botswana's food law [36]. In South Africa, insect (termites and black soldier fly maggots) farming is mainly carried out for use as animal feed [69]. Recently, the Kenya Bureau of Standards (KEBS) approved three National Standards that will guide the primary production of edible insects and their processed by-products. Guidelines for insect farmers on how to ensure the safety of the harvested produce by specifying the necessary minimum infrastructure and environmental requirements are provided by KS 2921:2020 [51]. Meanwhile processed edible insects products requirements for food and feed are regulated in DKS 2922-1: 2020 [49] and DKS 2922-2: 2020 [50].

Production and economical aspects of edible insects

At first, edible insects were only taken from the wild and then processed on a household scale. Then the number of requests made the insects began to be kept for breeding and then sold. Researchers have begun to develop a lot of technology for rearing edible insects in several species [40]. Its relatively small size and rapid reproduction make insect breeding not requiring large areas of land and difficult handling [40]. One bowl of cricket eggs can produce 3 kg of adult crickets, while in the cultivation area which can consist of 450 tubes it can produce 450 to 750 kg per harvest cycle (45 days) [40]. The net profit from one cycle of harvesting crickets can generate up to 50% of gross revenue if sold to collectors and can earn more if selling directly to the retail market [40]. It is estimated that the net profit that can be obtained from a 60 m2 breeding plot can be as much as $1250 or about $21/m2/year [39]. The profit depends on the size of the breeding grounds [40]. In addition, the price of crickets will also continue to increase along with the stage of growth [40].

Table 3. Comparison of feed conversion, water, global warming potential and land required to produce 1 kg of poultry, pork, beef and insects

Tabela 3. Porównanie konwersji paszy, wody, współczynnika ocieplenia globalnego i terenu potrzebnego do wyprodukowania 1 kg drobiu, wieprzowiny, wołowiny i owadów

Species	Edible share [%]	Feed conversion animal food (kg) /live weight	Global warming potential (CO_2-eq)	Water footprint water [l] /protein [g]	Land use area [m2] /protein [kg]
Beef	40	25	88	112	201
Pork	55	9.1	27	57	55
Poultry	55	4.5	19	34	47
Insects	80	2.1**	14*	23*	18*

*mealworms **cricket

Source: [27, 63, 74, 97]

Źródło: [27, 63, 74, 97]

Edible insects can be reared and harvested throughout the year, almost all parts of their body can be consumed, have high fertility and growth rates, and are more efficient in converting the substrate they consume into body mass [27]. According to Imathiu [43], edible insects have a high feed conversion efficiency value, one example is crickets which have a higher efficiency of converting feed into „meat" compared to poultry (2x), pigs (4x) and livestock (12x).Table 3 compared the conversion of feed, water, global warming potential and land required to produce 1 kg of poultry, pork, beef and insects.

Environmental impact of edible insects

Apart from their economic and nutritional value, insects have great potential in solving environmental problems. Livestock production is considered the sector that has the most negative impact on the ecology of global warming compared to other anthropogenic activities, both directly and indirectly (72-78% of total agricultural emissions) [99]. Insects are one of the solutions to the growing issue of climate change [38]. One of the quantitative methods for assessing greenhouse gas (GHG) emissions and other environmental parameters (such as land use and energy) is LCA (Life Cycle Assessment), in which these parameters will be calculated during the life cycle of a product [99]. Based on this LCA analysis, mealworms produce the least amount of GHG compared to other animal production [74]. The same thing was also shown by Dobermann et al. [14] which states that insect breeding produces the least amount of GHG compared to standard size large livestock and is equivalent to chickens per kilogram basis. This is due to less land use and less carbon emissions and emissions than other food sources from the agriculture and livestock sector [27] (Table 3). So that the development of insects as nutritious food is expected to suppress the use of other nutritional food sources that produce higher GHGs.

Farming and rearing technology of edible insects

Wild harvesting of insects is the most frequent method of collecting insects in most nations. In certain cases, the costs of insects might be far higher than those of meat [79]. Furthermore, according to seasonal and regional differences, insects may not be present in the wild all year round due to the lack of available resources [79]. As a result, industrial scale insect production, supported by sustainable insect breeding, farming, and processing technology, can reduce the limits on insect availability while also lowering the price of edible insects on the market [79]. Considering that growing or farming insects is now a modest component of the edible insect business, the consequences for the sector's long-term viability are currently uncertain [79]. Habitat conservation is one of the environmental advantages of farming, but the natural environment must be preserved as a source of regeneration and as a safety net, and it will continue to be crucial for local food supply and livelihoods. Given the increased interest in insect raising for commercial purposes, it will be necessary to make significant steps to ensure that the supply of insects does not damage the environment [79].

Food insects now provide a relatively small but rapidly expanding niche in the food market [26] and gathering insects in the wild will soon be insufficient to fulfill demand in the near future. Pesticide usage (*Aegiale hesperiaris* in agave) and environmental degradation (pollution by aquatic Hemiptera) can cause ecosystem deterioration in the wild [80]. It follows that to make insects a sustainable nutritional component for humans, enormous amounts of insects must be produced on a continuous basis, and both farming and processing must be automated.

From a small single cage to a large semi-automated factory, there are many different scales at which insect farming can actually occur [79]. Developing insect factories may lead to the usage of fewer species, but the small farm model has the ability to grow a greater variety of insects, reduce genetic diversity loss, and reduce the likelihood of an insect illness spreading across a colony [78]. As a result, insect farming for food and feed is becoming a more popular economic venture [78]. In addition, there is an increasing international interest in utilizing insects as feed since global demand is increasing and the supply of fishmeal is decreasing, resulting in the need to discover acceptable alternatives, such as insects, that can be farmed in huge quantities [78].

When evaluating insect rearing, it is important to determine the aspects that influence the substrates or feed used, as well as the conditions in which the insects are placed [78]. These considerations differ based on the bug species in question [78]. It just takes a few days to raise black soldier flies to maturity, but it takes several months to produce crickets to maturity. The temperature of the living environment has an influence on the rate of growth [78]. The nutritional composition of feed is crucial; for example, a very little amount of protein is harmful to insect growth, whereas a large amount of protein results in an excessive generation of dry uric acid [95]. The selection of feed is a complex balancing act between the cost of the feed and the growth rate of the insect being raised. Suboptimal nutrition during pregnancy and lactation can result in increased vulnerability to illness and cannibalism in animals, as has been demonstrated in the case of crickets and mealworms. In order to properly house insects, it is necessary to consider the insect's food requirements. The components that are accessible in the feed have a significant function to play. The availability of these components is dependent on a variety of factors like as pH, moisture, airflow, particle size, and so on. The availability of nutrients in feed is increased for most insects when the particle size of the meal is reduced. A coarser substance, on the other hand, is chosen for easier rearing (both in terms of feeding and cleaning).

The effectiveness of the insect production system is critical to the viability of producing insects as a source of sustainable protein in the long term. As a result, the quality of the insect food has an influence on both the protein contribution and the ecological impact of the insect [59]. When fed grain-based diets on a scale of economic importance, populations of crickets were shown to have no improvement in protein conversion efficiency when compared to broiler chickens that were fed identical diets, according to the study [59]. However, broiler diets have been optimized for decades, and it is possible that the efficiency of cricket raising will rise as a result of better feed. Erens et al. [19] have proposed that farmed insects should have access to high-quality nutrients, be allowed to express natural behavior, be free of discomfort, pain, injury, and disease during the breeding process, and be housed in a breeding environment that is as close to their natural environment as possible in order to maximize

animal welfare. They also recommend killing ways that are guaranteed to result in quick death. Although freezing and deep frying are widely employed to eliminate insects, there has been little research on their influence on animal welfare and food quality [78]. The practice of mass insect raising for food and feed is still in its infancy, and greater research into the possibility of disease transmission is required [27]. However, due to the fact that insects are taxonomically distinct from humans as compared to conventional cattle, the danger of zoonotic infection is believed to be extremely minimal [78]. In general, the FAO recommends that when beginning mass raising, regardless of the insect species being raised, a parallel line should always be maintained in case of culture failures or crashes [27].

The most effective methods for ensuring insect survival and reproduction should be studied and developed, for example, providing food resources, creating suitable habitats, harvesting sustainably (for example, allowing repairs to ant and wasp nests), and employing semi-rearing techniques such as those used for wild silkworms, among other things [78]. Feasible strategies to assist in the conservation of insect populations include recording their importance to people's livelihoods, examining relationships between insect harvesting and the ecology, and enforcing existing regulations. It has been proposed that the development of rules regarding the use and trade of insects for human consumption in many countries may be delayed by the existing lack of clarity in the terminology used to describe insect consumption at the time of writing [11]. It is critical to have a clear and comprehensive legal framework in place to promote new approaches to moving from the size of domestic insect raising to the scale of industrial insect rearing [78].

Nutritional value of edible insects

The potential of insects as food cannot be separated from their nutritional content both in terms of quantity and quality. Hanboonsong et al. [40] stated that in general, edible insects can provide protein (20-70% of raw protein), amino acids (30-60%), fat (10-50%) and minerals and vitamins. The minerals and vitamins contained include phosphorus, sodium, iron, copper, zinc, manganese, potassium, vitamins B1 and B2 and niacin [40]. However, there are several challenges in terms of food safety that need to be considered, namely the content of anti-nutritional compounds, allergens, biological hazards and other chemical hazards [43]. So that producers of edible insects are expected to be able to follow local regulations regarding food products. In addition, just like other food products, edible insects must also be maintained in hygienic conditions and continuously controlled for nutritional content and taste in order to maintain their quality [100]. The nutritional content of edible insects will affect several factors, including: the type of species and its processing [40], growth stage [52], gender [33; 73] and external factors such as weather, food, and the habitat of the edible insects [39].

Protein is not only assessed in terms of quantity, but also in terms of quality. The quality of protein from various food sources varies, depending on the content of essential amino acids that are important in physiological needs and nitrogen balance and bioavailability in the human body [15; 87]. Since 1989, FAO has recommended the Protein Digestibility Corrected Amino Acid Score (PDCAAS) method to assess protein quality, in which the limiting amino acid value is multiplied by protein digestibility [26]. However, this PDCAAS method has limitations where the calculation is carried out by assuming that all amino acids have the same digestibility as the whole protein (crude protein) [60]. Whereas each amino acid has a bioavailability that can only be determined accurately at the end of the small intestine (ileum) and fermentation in the hind intestine can affect the fecal excretion of amino acids, so there can be differences in the bioavailability of each type of amino acid [104]. According to FAO experts, protein quality is considered good if the value ranges from 75.0 to 99.9% and is considered very good if the value reaches 100% or more [26].

Research conducted by Ghosh et al. [34] which analyzed the nutritional profile of 5 types of commercial edible insects (3 beetle species; *Allomyrina dichotoma*, *Protaetia brevitarsis*, *Tenebrio molitor*, and 2 cricket species; *Teleogryllus emma, Gryllus bimaculatus*) in South Korea, showing that there are 17 types of amino acids (8 essential, 1 conditionally essential and 8 non-essential) and 26 fatty acids (12 SFA, 6 MUFA and 8 PUFA), where in addition to the amino acid methionine, other amino acids meet the protein recommendations of FAO/WHO/UNU [103]. Compared to other animal proteins (chicken meat and eggs), crickets show superior nutritional value with a higher content of protein, minerals (iron, zinc and magnesium) and fat with less SFA, but higher PUFA content (except in *A. dichotoma*) [34]. According to Payne et al. [76], the nutritional profile of edible insects has a wider variety than the type of meat that is often consumed, so that insects as food have the potential to overcome the problem of malnutrition. The same thing was stated by [6] in a study analyzing the nutritional profile of 3 types of edible insects in Nigeria (*Zonocerus variegatus*, *Macrotermes bellicosus* and *Cirina forda*) which turned out to have adequate nutritional content and can be used as an alternative food source to fight the problem of malnutrition. In addition, in terms of the proportion of macronutrient composition, insects can provide equivalent nutrients, not only compared to meat, but also from other food sources such as shellfish, nuts, vegetables and even fruit [82]. Other functional attributes of edible insects are also potential to be developed by the food industry as food and feed enrichment and fortification materials [6]. Table 4 shows the application possibilities of edible insects in different types of food.

CONCLUSIONS

Edible insects are a potential source of nutritious food, especially as a protein alternative. There are also positive aspects regarding the economic and environmental impacts of using edible insects as protein alternatives in the future. Despite the emerging opportunities, there are still some restrictions and limitations to the industrialization of edible insects in food products, from the breeding, processing and promotion of edible insects to their acceptance among consumers. Regulations on the use of edible insects still vary around the world, although local regulations have been applied in some areas. It is also important to carry out detailed research and deeper analysis on the economic and environmental aspects related to the use of edible insects as a future alternative to

Table 4. Insects as a food – examples from the market

Tabela 4. Owady jako żywność – przykłady z rynku

Type of product	Name of product	Company name	Country	Species of insect
Bar (protein bar, energy bar)	Jimini's Protein Bars Fig & Chocolate	Jimini's	France	Cricket
	Insect Protein Bars	Essento	Germany	Cricket
	Altimate Protein Bar	Altimate	Singapore	Cricket
Beer	Grasshopper Saison	Brouwerij De Molen	Netherland	Grasshopper
	Crna Smrca	Insektarij	Croatia	Cricket
Bread	Mayu no Tayori Croissant, Mayu no Tayori Madeleine	Pasco	Japan	Silkworm
	Sirkkaleipä	Fazer	Finland	Cricket
Burger	Bux Burger	Bug Foundation	Germany	Buffalo Worm
Candy and chocolate	Edible Insects & Bug Candy	Meat Maniac	USA	Cricket, Larvet, Ant
	Silkworm Pupae Chocolate Covered	Thailand Unique	Thailand	Silkworm
	InsectNside	Hotlix	USA	Cricket, Worm, Ant
Cookies	Chocolate Chirp Cricket Protein Cookie Mix	Chirps	USA	Cricket
Crackers	Small Giants, Cracker Bites	Jimini's	France	Cricket
Crips/Chips	Chirps Cricket Protein Chips	Chirps	USA	Cricket
Gourmet	Hiroshima Crickets	Takeos	Japan	Cricket
Granola	Bugbites	Entis	Finland	Cricket
	Granola	Jimini's	France	Buffalo Worm
Meat replacement	Sirkkis	Entis	Finland	Cricket
Milk	Ento Milk	Gourmet Grubb	South Africa	Cricket
Oil	Buffalo Mealworm Oil (BMO)	AdalbaPro	Netherland	Buffalo Mealworm
Pasta	Aldento, La Base D'un Repas Sain Et Équilibré	Goffard Sisters	France	Mealworm
	Protein Pasta	Jimini's	France	Buffalo Worms
Pasta sauce	Mealworm Bolognese, Cricket Bolognese	One Hop kitchens	Canada	Mealworm, Cricket
Powder/Flour	Cricket Protein Powder	Eat Grub	United Kingdom	Cricket
Sausages	High Protein Sausages	The Bricket	Thailand	Cricket
	Sirkka Nakki (Cricket Sausages)	Mattila Bros	Finland	Cricket
Shots	Bugs'n Shot	Syngja	Denmark	Cricket
Spices/seasoning	Sal de gusano, Gusano de Maguey	Real de Oaxaca	Mexico	Agave Worm
Soft drinks	Tagame cider	Takeo	Japan	Giant Waterbug
Spirits	Mezcal Worm (Mezcal Con Gusano)	Monte Alban	Mexico	Worm
	Anty Gin, Ant Snaps	Nordic Food Labs	Denmark	Ant
Tsukudani	Inago Tsukudani	Inago Tsukudani	Japan	Hornet larvae, Grasshopper

Source: Own elaboration based on [1, 2, 3, 4, 5, 9, 10, 16, 17, 18, 20, 28, 35, 42, 44, 46, 47, 58, 61, 62, 64, 71, 75, 81, 83, 91, 92, 93, 94, 108]

Źródło: Opracowanie własne na podstawie [1, 2, 3, 4, 5, 9, 10, 16, 17, 18, 20, 28, 35, 42, 44, 46, 47, 58, 61, 62, 64, 71, 75, 81, 83, 91, 92, 93, 94, 108]

protein. What can be seen is that the edible insect industry is growing strongly, and it is not impossible that many more products using edible insects will be on the market in the future.

WNIOSKI

Jadalne owady stanowią potencjalne źródło odżywczej żywności, zwłaszcza jako alternatywy białka. Istnieją również pozytywne aspekty dotyczące ekonomicznych i środowiskowych skutków wykorzystania jadalnych owadów jako alternatywy dla białka w przyszłości. Pomimo pojawiających się możliwości, nadal istnieją pewne ograniczenia i restrykcje w uprzemysłowieniu jadalnych owadów w produktach spożywczych, od hodowli, przetwarzania i promowania jadalnych owadów po ich akceptację wśród konsumentów. Regulacje dotyczące wykorzystania owadów jadalnych nadal różnią się na całym świecie, chociaż w niektórych obszarach zastosowano lokalne regulacje. Ważne jest również, przeprowadzenie szczegółowych badań i głębszych analiz na temat ekonomicznych i środowiskowych aspektów związanych z wykorzystaniem owadów jadalnych jako przyszłej alternatywy dla białka. To co można zauważyć to, że branża związana z produkcją owadów jadalnych mocno się rozwija i nie jest wykluczone, że w przyszłości pojawi się na rynku znacznie więcej produktów z wykorzystaniem jadalnych owadów.

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