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POTENTIAL BENEFITS OF INSECT PROTEIN IN PREVENTING OVERWEIGHT AND OBESITY

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Abstract: Obesity in children and adolescents is one of the most serious health challenges of the 21st century, and the number of overweight and obese people is steadily increasing. In recent years, entomophagy, or the consumption of insects, has been proposed as an alternative source of protein with economic and environmental advantages over traditional meat production. Edible insects have high nutritional value. They are rich in protein, recommended fats, vitamins, and minerals. Moreover, numerous animal studies show insect protein can slow weight gain, improve the immune response, reduce inflammation, and benefit energy metabolism. Despite the challenges of promoting and accepting insect protein, its health and environmental benefits may make it an essential part of a balanced diet in the future. Including insects in the diet can help overcome obesity-related health problems, potentially help control weight and reduce the risk of obesity-related diseases. However, further research, including clinical trials, is needed to confirm the health benefits of insect protein. Educational campaigns can help break down cultural barriers and increase the acceptance of entomophagy.

Key words: edible insects, entomophagy, insect protein, nutritional value of insects, obesity, health benefits of insects, neophobia

INTRODUCTION

Obesity and overweight among children and adolescents are one of the most serious health challenges of the 21st century. According to the World Health Organization (WHO), the number of overweight and obese children and adolescents is on a clear upward trend. In 1975, the number of obese children was 11 million, while in 2016, it had risen to 124 million. In Poland, the problem affects about 10% of young children (1–3 years), 30% of early school-age children, and almost 22% of adolescents up to age 15 [1]. The increasing rate of overweight and obesity among children represents a major public health challenge, influencing the development of numerous physical and mental illnesses in childhood, which can persist into adulthood. Obesity increases the incidence of comorbidities, such as stroke, atherosclerosis, myocardial infarction, cardiovascular disease, diabetes, hypertension, and hyperlipidaemia [2].

Various obesity treatment regimens have been proposed, including physical activity, appropriate diet, and medication to aid weight reduction. Most known anti-obesity drugs suppress the appetite, reducing the absorption of components or energy sources, i.e., sugars or fats, and are often accompanied by adverse side effects [3]. It is, therefore, extremely important to step up research to identify natural products that offer safe effects to support therapy in the fight against being overweight. According to Sanyaolu et al. [4], obesity in childhood and adolescence is caused by a mismatch between energy intake and expenditure, regardless of genetic factors.

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The daily diet's amount and composition of macronutrients (carbohydrates, fats, and proteins) determines the total energy expenditure. Proteins provide less energy than an equivalent amount of fats, and their percentage contribution in a healthy, balanced diet is around 20%. In comparison, carbohydrates contribute 50% and fats 30% [5]. It is also important to remember that daily protein intake in childhood is essential for normal growth and development and varies with age, sex and physical activity [6]. As shown in a study in mice [7], when diets are low in protein energy, a mechanism known as protein leverage stimulates a compensatory increase in food intake to achieve a specific absolute protein intake. Saner et al. [8] showed that small changes in protein intake may have been a major contributor to the obesity epidemic in the USA between 1961 and 2013. A recent study by Larsen et al. [9] found that high-protein and low-glycaemic-index diets were more effective in maintaining weight loss and improving metabolic parameters than low-protein diets. In a study conducted by Saner et al. [8] on a group of obese children and adolescents aged six to eighteen years, it was found that changing the amount of protein in the diet could help reduce the total energy intake in obese adolescents. Hall's (2019) population-based study [10], which examined trends in macronutrient composition over the past four decades in the United States, found a decrease in the percentage of energy intake from protein sources and an increase in total energy intake, increasing BMI. One reason for this phenomenon is the increasing popularity of highly processed foods, which contain only 9.5% of energy from protein sources [13]. According to Hall [10], the consumption of large amounts of highly processed foods is a major cause of the growing obesity epidemic. As shown by Saner et al. [8], only a balanced macronutrient composition in the diet of children and adolescents can help combat the problem of obesity.

When discussing obesity, it is also worth mentioning the use of the satiety index [11] and the effect of individual nutrients on the body's satiety level, i.e. the feeling of fullness after a meal. A diet based on this index can be an alternative to restrictive diets. Most studies on the effect of protein on satiety have found that protein has a more significant effect on satiety than carbohydrates or fats. Current data suggest that increasing the protein intake plays a key role in satiety [12].

Given the various proposals for using currently available foods, it is worth considering edible insects in the diet. On the one hand, they can be a potential source of high-quality protein [13, 14, 15, 16], and on the other hand, they can be an effective component of low-carbohydrate diets [17, 18, 19]. Of all food components, protein and dietary fibre [20] have the strongest satiating properties. Protein is thought to release neurochemicals that suppress appetite [21]. It is hypothesised that insect protein-induced satiety is mediated by the release of specific neurochemicals and hormones that regulate appetite and food intake. Key neurochemicals involved in this process include serotonin, dopamine, cholecystokinin (CCK), and glucagon-like peptide-1 (GLP-1). The mechanisms by which insect protein induces satiety include stimulating these hormones and neurochemicals. Insect protein ingestion triggers the release of CCK and GLP-1, which send signals to the brain to promote satiety and reduce appetite. In addition, insect protein can affect the brain's reward system by increasing dopamine levels, increasing satiety and reducing food intake. These mechanisms suggest insect protein may effectively regulate appetite and control weight [22, 23]. A high-protein meal increases the likelihood of reducing the energy content of the next meal by up to 25%. In addition, carbohydrate reduction may also have a positive effect on satiety, as carbohydrates have been cited as the ingredient with the lowest satiety potential [24, 25, 26]. Skotnicka et al. [21], based on a study of insect food intake in 71 volunteers, found that pancakes with 30% flour from *Alphitobius diaperinus* and those with 20% and 30% flour from the house cricket (*Acheta domesticus*) were the most satiating. They concluded that protein content had the greatest effect on inducing satiety. The results support the hypothesis that insect-based foods could be an ingredient in diets for treating obesity, for carbohydrate-restricted diets, and as alternative protein sources [26].

Insects have been valued as a food source in many cultures for centuries. Although the topic has gained renewed attention recently, Meyer-Rochow [27] proposed the consumption of insects as an alternative food and feed source nearly 50 years ago. It is currently estimated that over 2 billion people regularly consume insects [28].

Insect protein offers several environmental benefits, making it a sustainable alternative to traditional meat production. Firstly, insect farming requires significantly less water compared to conventional livestock farming. For instance, producing 1 kg of insect protein requires about 1 litre of water, whereas producing the same amount of beef protein requires approximately 22,000 litres. This drastic reduction in water usage makes insect farming a more sustainable option. Insect farming also needs less land than traditional livestock farming. Insects can be farmed in vertical systems, which allows for efficient use of space [15, 16, 24, 28]. This means that insect farming can be conducted in urban areas and other locations where space is limited, further contributing to its sustainability. Insect production also generates significantly fewer greenhouse gases compared to traditional meat production. For example, insect farming's methane and nitrous oxide emissions are much lower than cattle farming emissions

[28]. This reduction in greenhouse gas emissions helps mitigate climate change and reduces the environmental footprint of food production. Moreover, insects can be fed organic waste, reducing waste and improving resource efficiency. For example, Housefly larvae (*Musca domestica*) can be fed kitchen waste, converting it into valuable protein. This reduces the amount of waste that ends up in landfills and creates a sustainable source of protein. Insects have a high feed conversion efficiency, meaning they convert a more significant proportion of their feed into protein [15, 24, 28]. This efficiency makes insect farming a more resource-effective way to produce protein.

However, the introduction of insects for human consumption has met with resistance, particularly in Europe, mainly due to cultural issues. While cultural issues are indeed relevant to the low consumption of insects in Europe, they are not the only challenge. Legislative issues are also a significant barrier. The European Union has strict rules for approving and marketing novel foods, including insects. The Novel Foods Regulation (EU) 2015/2283 requires extensive safety assessments and authorisation procedures before insects can be marketed as food. While ensuring consumer safety, this regulatory framework can be time-consuming and costly for producers, limiting the availability and diversity of insect-based products on the market [15, 16]. In addition, there is a lack of harmonisation of regulations across European countries, which can create additional barriers for producers wishing to enter multiple markets. For example, some countries may have more lenient regulations while others impose stricter controls, leading to inconsistencies and confusion in the industry [19]. In conclusion, while cultural issues are important, regulatory challenges also play a key role in the low consumption of insects in Europe. Tackling cultural and regulatory barriers is therefore essential to increase the acceptance and consumption of insect-based foods.

Edible insects have great potential as a food source. Their sustainability, nutritional value, economic viability, and low environmental impact make them attractive for addressing global food security and sustainability challenges. This review aims to synthesise and critically evaluate the current knowledge on the potential use of insect protein in the prevention of overweight and obesity, and to identify gaps in the literature that require further research.

NUTRITIONAL VALUE OF EDIBLE INSECTS

The reasons for promoting insects as a source of nutrients in the diet are increasingly supported by a growing body of scientific research. The number of publications on entomophagy increased from 16 in 2001–2010 to 49 in 2011–2015, and 50 articles were published between 2016 and September 2017. Given this trend, it is reasonable to estimate that over 200 studies have been published from 2014 to 2024 [29].

Current research mainly focuses on edible insect species approved for consumption. This is due to food safety considerations and legal regulations determining which insect species can be used as food. The most commonly studied species in the scientific literature are *Tenebrio molitor*, *Acheta domesticus*, *Hermetia illucens, Bombyx mori, Imbrasia belina* and *Rhynchophorus phoenicis* [30, 31].

Edible insects are rich in protein and beneficial fats, vitamins and minerals, making them a valuable dietary component. Compared to traditional sources of protein, such as meat, insects can provide protein with high biological value at a lower calorie load (Tab. 1). According to Zeng & Li (2021) [40], a higher protein intake, including insect-derived protein, can affect the composition of the gut microbiome, which in turn can affect metabolic health and weight control. The average amount of protein in edible insects ranges from 10% to 70% of dry weight, which is higher than some plant products such as soya and lentils [24]. For example, the protein content of fresh edible butterfly caterpillars and chicken meat is 28 g/100 g and 21 g/100 g fresh weight, respectively [32]. The wide range of protein content in edible insects is due to the huge number of species and their diversity, developmental stages (larvae, pupae, adult insects), culture conditions, processing methods and analytical methods (Tab. 1). The content of essential amino acids varies depending on the species and developmental stage of the insect. It ranges from 46% to 96% of the total amino acids [32].

Insect protein contains all 20 amino acids, fully meeting the adult human requirement for these components. Insect protein is a good source of valine, histidine, phenylalanine and tyrosine, and in some species also tryptophan, lysine and threonine, although in varying amounts depending on the species [40]. According to Malla et al. [41], the tryptophan content ranges from 0.5% to 1.5%, and according to a study published in the International Journal of Biological Macromolecules, the amino acid profile of insects may be deficient in it [42]. The amino acid indices in edible insects such as *Tenebrio molitor* and *Alphitobius diaperinus* are comparable to those found in soybeans and bovine casein [43]. An undoubtedly important feature is insect protein's digestibility, which is comparable to milk, soya, or casein, ranging from 54% for *Tenebrio molitor* to as high as 98% for some South American insect species [40]. On average, these values are similar to those reported for egg white (95%) or beef (98%), and higher than many plant proteins [44].

Table 1. Chemical composition, nutritional value and vitamin content of selected edible insects and conventional protein sources.

Insect species and conventional protein sources	Protein (%)	Fat (%)	Carbohydrates (%)	Fibre (%)	Vitamins and minerals (mg/100g)	Ref.
Tenebrio molitor	47.0	30.0	6.0	5.0	Fe: 5.0, Zn: 10.0, Ca: 20.0, Vit B12: 1.2, Vit A: 0.1	[30,26]
Hermetia illucens	42.0	35.0	7.0	6.0	Fe: 4.5, Zn: 8.0, Ca: 18.0, Vit B12: 2.3, Vit A: 0.2	[30,26]
Acheta domesticus	70.0	12.0	5.0	2.0	Fe: 3.0, Zn: 9.0, Ca: 15.0, Vit B12: 5.4, Vit A: 0.3	[30,26]
Bombyx mori	55.0	28.0	8.0	4.0	Fe: 6.0, Zn: 11.0, Ca: 22.0, Vit B12: 3.1, Vit A: 0.2	[30,26]
Schistocerca gregaria	62.0	17.0	10.0	3.0	Fe: 4.0, Zn: 7.0, Ca: 19.0, Vit B12: 1.8, Vit A: 0.1	[30,26]
Alphitobius diaperinus	60.0	18.0	6.0	5.0	Fe: 4.0, Zn: 8.0, Ca: 16.0, Vit B12: 2.0, Vit A: 0.2	[33,26]
Locusta migratoria	50.4	19.6	4.8	15.7	P: 29.6, Ca: 2.2, Vit B12: 1.5, Vit A: 0.1	[34,26]
Macrotermes nigeriensis	20.4	36.8	18.8	15.2	Fe: 95.6, Zn: 4.2, Ca: 20.0, Vit B12: 0.9, Vit A: 0.1	[35,26]
Gryllus bimaculatus	60.0	23.0	5.0	2.0	Fe: 3.0, Zn: 9.0, Ca: 15.0, Vit B12: 4.0, Vit A: 0.2	[36,26]
Musca domestica	57.0	25.0	6.0	4.0	Fe: 5.0, Zn: 10.0, Ca: 18.0, Vit B12: 2.5, Vit A: 0.2	[37,26]
Protaetia brevitarsis	63.0	15.0	8.0	5.0	Fe: 4.5, Zn: 8.0, Ca: 17.0, Vit B12: 3.0, Vit A: 0.2	[38,26]
Chicken	27.0	14.0	0.0	0.0	Fe: 1.3, Zn: 1.0, Ca: 11.0, Vit B12: 0.6, Vit A: 0.0	[31,39]
Beef	26.0	20.0	0.0	0.0	Fe: 2.6, Zn: 4.0, Ca: 12.0, Vit B12: 2.5, Vit A: 0.0	[31,39]
Soybeans	36.0	20.0	30.0	9.0	Fe: 15.7, Zn: 4.9, Ca: 277.0, Vit B12: 0.0, Vit A: 0.0	[31,39]
Eggs	13.0	11.0	1.0	0.0	Fe: 1.2, Zn: 1.0, Ca: 50.0, Vit B12: 1.1, Vit A: 0.3	[31,39]
Fish (salmon)	20.0	13.0	0.0	0.0	Fe: 0.8, Zn: 0.6, Ca: 20.0, Vit B12: 3.2, Vit A: 0.1	[31,39]

Source: own elaboration based on [31, 39].

The fat content of insects ranges from 8 to 70% based on dry weight and varies considerably depending on the species and stage of development. Butterfly larvae (Lepidoptera) and bugs (Heteroptera), have a significantly higher fat content than other edible insects. In contrast, adult insects, compared to their larvae or juvenile forms, are characterised by a fat content of less than 20% [45]. The fatty acid composition is comparable to that of poultry and fish fat. It is characterised by a relatively high content of C18 fatty acids, including oleic, linoleic and linolenic acids. It is high in many species and high in saturated fatty acids, especially palmitic acid [44]. Mature insects are particularly valued for their rich content of polyunsaturated fatty acids, exceeding traditional sources such as pork and beef. Insects belonging to the order Orthoptera, such as the *Locusta migratoria*, are an exceptional source of linoleic acid. On the other hand, butterfly larvae have a particularly high content of α-linolenic acid [45]. The higher fat content of butterfly and bug larvae is related to their energy requirements during growth and metamorphosis. In contrast, adult insects have lower fat levels because their main purpose is reproduction and flight [46].

Insects are not a rich source of carbohydrates. Their average content ranges from 6.71% in bugs to 15.98% in cicadas, and is mainly found in the form of chitin, which is classified as a polysaccharide. As an exoskeleton component, chitin is structurally similar to cellulose [47]. The content of chitin in different insect species can vary considerably and it can be digestible by humans, thus having nutritional and health benefits beyond improving gut health as a prebiotic [48]. Oliveira et al. [49] showed that chitin and its derivative, chitosan, exhibit fibre properties that can act as prebiotics [50], selectively stimulating the growth and activity of beneficial bacteria in the colon. In insects, chitin forms a complex mainly with proteins and lipids, affecting their digestibility [49]. Chitin, a linear polymer consisting of N-acetylglucosamine units, and their derivative, chitosan, formed by the deacetylation of chitin and containing a higher number of glucosamine units, exhibit important fibre properties. The deacetylation process increases the solubility of chitosan in acidic solutions and gives it a higher positive charge, which affects its ability to bind lipids in the human gastrointestinal tract [51].

Insects are also a source of micronutrients such as copper, iron, magnesium, manganese, phosphorus, selenium and zinc. According to Zhou et al. [26], the Orthoptera and Coleoptera species contain higher levels of chemically active calcium, copper, magnesium, manganese, and zinc than beef, with crickets, in particular, having higher iron bioavailability. Some studies have confirmed that insect consumption can provide a high percentage of humans' daily recommended mineral intake, particularly for iron [49]. *Macrotermes nigeriensis*, a genus of termites that is consumed in many parts of the world, especially in Africa, Asia, Australia and Latin America [52], contains 95.6 mg of iron per 100 g of dry weight [49], which is much higher than the iron content of pork loin on the bone (only 1 mg/100 g), veal shoulder (2.9 mg/100 g) or pork liver (18.7 mg/100 g) [53]. Termites are also a popular food source in Kenya, especially in rural regions. Research has shown that about 80% of respondents in Kenya have tasted termites, and 55% regularly buy termite food products such as dried and roasted ones. Termite consumption in Kenya can range from a few times a month to several times a week, depending on availability and culinary traditions [54].

Insects are a rich source of both water-soluble and fat-soluble vitamins, including significant amounts of vitamin B12 (Tab. 1) For example, the vitamin B12 content ranges from 1.08 µg/100 g in whiteflies to 13.2 µg/100 g dry weight in cockroaches (Blattodea) [40, 55].

OVERWEIGHT AND OBESITY-RELATED HEALTH EFFECTS OF CONSUMPTION OF SELECTED INSECT SPECIES

The solution to obesity and overweight lies not only in reducing calorie intake but also in improving the quality of the diet. As mentioned at the beginning of this article, the high protein content of insects promotes satiety, which helps to reduce the overall food intake and control weight. Unlike the fats found in meat products, insects are also a valuable source of unsaturated fatty acids. They are also low in carbohydrates, which, when consumed in excess, can lead to weight gain and metabolic disorders. The nutritional profile of insects supports muscle maintenance and growth, which is essential for metabolic health and effective weight management [45].

Numerous studies have shown (Tab. 2) that certain insect-derived substances regulate lipid metabolism and blood lipid levels, with anti-obesity effects. In vivo studies using *Tenebrio molitor* larvae have shown that they reduce lipid accumulation and triglyceride levels, leading to weight loss in obese mice [26]. Daily administration of *Tenebrio molitor* larvae powder to obese mice fed a high-fat diet inhibited weight gain and reduced visceral fat [56]. The powder also reduced hepatic steatosis and decreased plasma levels of liver enzymes such as alanine aminotransferase and aspartate aminotransferase, which are indicators of liver damage.

Table 2. Health effects of consumption of selected insect species in the context of overweight and obesity

Insect species	Health effects related to overweight and obesity	Ref.
Tenebrio molitor	Reduced lipid accumulation, reduced triglyceride levels, improved blood lipid profile	[57]
Hermetia illucens	Reduced body weight, reduced visceral fat accumulation, improved lipid metabolism	[58]
Acheta domesticus	Increased feeling of satiety, improved lipid profile, lowered blood glucose levels	[59]
Bombyx mori	Regulated lipid metabolic processes, reduced fat accumulation, improved insulin sensitivity	[60]
Schistocerca gregaria	Lowered cholesterol levels, improved lipid profile, reduced body weight	[61]
Alphitobius diaperinus	Reduced fat accumulation, improved lipid metabolism, reduced blood glucose levels	[62]
Locusta migratoria	Reduced body weight, improved lipid profile, lowered blood glucose levels	[63]
Macrotermes nigeriensis	Reduced fat accumulation, improved lipid metabolism, reduced blood glucose levels	[64]
Gryllus bimaculatus	Increased feeling of satiety, improved lipid profile, lowered blood glucose levels	[65]
Musca domestica	Reduced fat accumulation, improved lipid metabolism, lowered blood glucose levels	[66]
Protaetia brevitarsis	Reduced body weight, improved lipid profile, lowered blood glucose levels	[67]

Source: own elaboration based on [57, 58, 59, 60, 61, 62, 63, 64].

A study by Park et al. [68] confirmed these observations. Using *Tenebrio molitor* larvae powder in the diet of mice, the authors reported reductions in body weight, subcutaneous and visceral fat volume, hepatic adipocyte accumulation, adipocyte size, leptin levels, levels of adipogenesis-related genes and plasma concentrations of total cholesterol, triglycerides and glucose. In another in vivo study in spontaneously hypertensive rats fed a diet based on *Tenebrio molitor*, a slight reduction in fat mass was observed [69]. The reduction in visceral fat improved hepatic insulin action and reduced the expression of inflammatory cytokines.

Allomyrina dichotoma larvae extract reduced the serum triglyceride and leptin levels in obese mice and reduced body weight gain, organ weights and adipose tissue volume in a dose-dependent manner [70]. In a study in a rat model fed a high-fat diet, it was observed that ethanolic extracts from *Gryllus bimaculatus* exhibited anti-obesity properties. Rats that received the extract for two months showed a reduction in fat mass, especially abdominal fat [71]. The peptides of the mulberry silkworm pupa have hypolipidemic effects, regulating lipid metabolic processes in the body, inhibiting the formation of fat in preadipocytes and reducing lipid accumulation and adipocyte size, which helps to combat obesity [72].

Other studies have shown that protein hydrolysate from silkworm larvae increases glucose uptake and reduces fat accumulation by increasing leptin expression [72]. Ethanolic extract of *Oxya chinensis* locusts slows carbohydrate digestion and glucose uptake by inhibiting the activity of carbohydrate digestive enzymes, thereby reducing postprandial hyperglycaemia induced by dietary carbohydrates [67]. It has been observed in mice that a protein-enriched extract of housefly *Musca domestica* larvae reduces plasma triglyceride, total cholesterol and low-density lipoprotein levels while increasing high-density lipoprotein levels [56].

Feeding rats a meal containing various amounts of house fly pupae reduced visceral fat [73]. These effects were probably stimulated by the chitin, monounsaturated fatty acids, and bioactive compounds in house fly pupae that have not been identified yet [73].

Chitosan isolated from *Acheta domesticus* has been shown to retain lipids. Its lipid-binding capacity is comparable to shrimp chitosan [74], which has been shown to exert anti-obesity effects by controlling body weight in pigs [46].

It has also been reported that cricket ethanol extract reduced body weight, intestinal fat and total cholesterol in mice given a high-fat diet for 14 weeks [75]. A study by Huang et al. [76] confirmed a significant reduction in food intake and fat accumulation in obese rats fed chitin, which prevented weight gain and significantly reduced serum lipids such as total cholesterol, triglycerides and low-density cholesterol.

Administration of *Protaetia brevitarsis* larvae extract to mice with high-fat diet-induced obesity reduced body weight, liver adipocyte count, and serum lipid levels [56]. A high-fat cricket-based diet in rats had beneficial effects on lipid metabolism and body fat content [51].

Recent studies have continued to explore innovative solutions to this growing problem. For instance, Rizou et al. (2022) [78] demonstrated that probiotic supplementation in the diet of Tenebrio molitor larvae significantly improved their nutritional profile, increasing the protein content and reducing fat levels – factors that may enhance their potential as a functional food ingredient in metabolic health. Additionally, Dreassi et al. (2017) [79] showed that the fatty acid composition of *T. molitor* can be modulated through dietary interventions, improving the balance of polyunsaturated fatty acids, which are known to support lipid metabolism and reduce inflammation. These findings support the use of mealworm protein as a promising dietary component in obesity prevention and lipid profile improvement. Furthermore, Kang et al. (2023) [62] demonstrated that the inclusion of *Tenebrio molitor* and *Alphitobius diaperinus* in a high-fat diet significantly altered the gut microbiota composition in obese mice. These changes were associated with improved metabolic parameters, including reduced body weight gain and enhanced lipid metabolism. This study highlights the potential of insect-based diets to modulate host metabolism through microbiota-dependent mechanisms.

The few human clinical studies on the consumption of edible insects provide valuable information on their impact on human health [29, 80]. These have shown, among other things, that the consumption of insect protein can lead to increased post-meal amino acid levels, suggesting its high bioavailability and potential as an alternative protein source. In addition, studies have shown that insect consumption can improve gut health by increasing gut microbiota diversity and reducing inflammation. They further confirmed that supplementation with chitosan, a chitin derivative, can lead to weight loss and improved lipid profile, which is important for preventing obesity and metabolic diseases. Finally, studies on insect protein intake have shown that it can improve metabolic health indicators such as blood glucose levels and lipid profile, suggesting its potential health benefits.

ADVOCATING INSECT PROTEIN AS A SUSTAINABLE AND EFFECTIVE STRATEGY FOR TREATING OVERWEIGHT AND OBESITY

Insect protein is increasingly seen as a good alternative and sustainable source. Despite the growing interest in edible insects, their promotion as a viable solution to combat obesity faces several challenges, especially in European countries. One of the main problems is public acceptance and poor promotion of the potential of edible insect-based products [81]. Convincing consumers to change their eating habits takes time and education. Information and education campaigns can help to break down cultural barriers and increase the acceptance of insect protein. This acceptance of insect-based foods among children, the next generation of consumers, is particularly under-researched, as most studies have targeted adults.

Previous consumer research in European countries shows a low acceptance of edible insect-based products. Most of these studies have been conducted in the Netherlands, Belgium and several other northern countries, where insect-based products have become commercially available in recent years [81, 82, 83]. The acceptance of insect-based foods is largely determined by food neophobia, which is the tendency to avoid unfamiliar or new foods [84]. Food neophobia plays a key role in accepting insects as food and the willingness to eat insect-based foods [86].

A study by Ainslee et al. [87] of 181 school-aged children found that Danish children showed a moderate willingness to try insect-based foods, suggesting potential in this segment of the population. In a study by Dupont and Fiebelkorn [88] on the attitudes and acceptance of young people from Germany towards the consumption of insects and farmed meat, the authors noted that of the children and adolescents who took part in the study, 70.9% had already heard that insects could be used as food and knew what this meant, while 22.4% had heard of the possibility of eating insects, but did not know exactly what this meant. Only 6.7% did not know that insects could be eaten. Of the respondents, 17.8% had eaten insects once and 5.3% several times. Only 0.1% stated that they regularly ate insects. In addition, the study showed that the respondents were more likely to eat burgers with lab-grown meat than burgers with insects.

Three focus group interviews conducted with children aged 4–5 years in a public kindergarten in Sweden concluded that using children's imagination and curiosity about new things, experimenting with insect-based products and ingredients in familiar dishes and discussing different ways of eating insects can increase children's acceptance of eating insects [89].

A study by Marquis [89] discussed how exposure and familiarisation with edible insects can influence adolescents' attitudes towards entomophagy. The activity, which involved 662 Canadian high school students, was shown to have a significant positive impact on the participants' acceptance of edible insects. These results can be used in promotional activities to accelerate the acceptance of edible insects. A study by Florence et al. [90] found that people were more likely to consume food products containing insects than whole insects, and the youngest were the most likely to consume insects. A study on the effect of educational interventions on attitudes and the willingness to consume insect-based foods was conducted by Szczepanski et al. [91]. After an educational class on 'Entomophagy and sustainability', the authors reported a slight increase in the willingness to consume insect-based foods. Attitudes appeared to be the strongest predictor of willingness to consume, while knowledge had no significant effect. The type of insect, the order of tasting, and children's food neophobia had a significant effect on food acceptance.

Szlachciuk and Żakowska-Biemans [92] studied the perception, beliefs, and willingness to consume insects among Polish consumers. The study included 1,000 respondents and found that dietary neophobia was a key factor influencing beliefs and perceptions of the consumption of insects and insect protein products. Respondents were more likely to consume insect protein products than visible insects. Sogari et al. [93] examined the relationship between the willingness to try insects and food neophobia among young adults in Italy. The study included 88 participants and found that males were more open to trying insects than females, and food neophobia was negatively correlated with a willingness to eat insects. Kinyuru et al. [94] studied the influence of food neophobia and socio-cultural factors on the consumption of edible insects in Uganda. The study included three insect species: locusts, African termites, and wingless termites. The results indicated that food neophobia and socio-cultural factors significantly impacted consumers' willingness to consume insects.

CONCLUSIONS AND FUTURE PERSPECTIVES

Obesity and overweight in children and adolescents is one of the most serious health challenges of the 21st century, and the number of overweight and obese people is steadily increasing, according to the World Health Organization (WHO). In the search for sustainable solutions, entomophagy has been proposed as an alternative protein source with economic and environmental advantages over traditional meat production. Insect protein is increasingly being explored as a potential tool in the fight against obesity.

Edible insects such as crickets, mealworm larvae and grasshoppers are characterised by high levels of complete protein, low carbohydrate contents and the presence of beneficial nutrients such as unsaturated fatty acids, vitamins, minerals, and non-digestible polysaccharides like chitin. Numerous studies suggest insect protein can effectively control body weight by increasing satiety and postprandial thermogenesis.

However, the introduction of insect protein into the diet faces several challenges, including social and cultural acceptance. Despite growing interest, edible insect-based products are still not very popular in European countries. Education and information campaigns are key to breaking down barriers and increasing consumer acceptance of insect protein, especially among more receptive consumers such as children and teenagers.

In conclusion, insect protein has the potential to be a valuable tool in the fight against obesity and overweight. However, its full potential requires further research, especially clinical studies, and educational and promotional activities in primary, secondary, and higher education. Increasing consumer acceptance of insects as sustainable food is key to promoting the regular consumption of insect-based foods.

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