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Physicochemical, Nutritional, Antioxidant, and Sensory Properties of Crackers Supplemented with Edible Insects

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Featured Application: The addition of edible insects to crackers in an amount of 5% improved the nutritional profile compared to the control sample. The crackers with edible insect powder were evaluated as acceptable, but some evaluators felt a foreign taste and aroma which resembled fish or mushrooms, or bitterness. Crackers with cricket powder addition had the best score (smell—balanced, and pleasant) compared to other samples containing insect powder.

Abstract: This study aimed to determine the physicochemical, nutritional, antioxidant, and sensory properties of crackers with the addition of edible insects. The analyses covered the contents of total dry matter, crude protein, fat and ash; amino acid composition and antioxidant activity (DPPH method); total polyphenol content; mineral compound composition (AAS); caloric value; and sensory profile (aroma, taste, general appearance, overall acceptability) of the durable pastry—crackers supplemented with 5% of powder of edible insects (cricket, mealworm, and grasshopper). Appropriate research methods were used for analyses. Studies have shown that the contents of dry matter, crude protein, fat and all amino acids detected were higher in the samples with the addition of insects compared to the control sample. The highest antioxidant activity was assayed in the sample with the addition of grasshopper powder. The highest content of total polyphenols was determined in the sample with the addition of mealworm. The addition of insects positively affected the content of mineral substances—especially zinc—in the sample with cricket powder addition. The results of this study show that edible insects are an attractive raw material, which can in future expand the assortment of food products available on the market and increase the nutritional benefits of enriched products.

Keywords: durable pastry; cricket; mealworm; grasshopper; benefits; food with added value

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1. Introduction

The consumption of insects, formally known as entomophagy, is not a new eating habit. Such habits are linked to culture and religion, and the consumption of insects can be encountered in Judaism, Christianity, and Islam. For example, locust (*Schistocerca gregaria*) is referred to as food in the Book of Leviticus. The first mention of entomophagy in Europe comes from *Historia Animalium*, written by Aristotle (384–322 AD), which indicates which stage of cicada is the tastiest and that the adult females taste best after fertilization, when they are full of eggs [1]. Today, the consumption of insects is a trend driven by ecological concerns. The European Union has set a target to reduce emissions by 55% by 2030 compared to the 1990 level and reduce the degradation of the natural environment caused by pollution. As a source of animal protein, insects are significantly less harmful to the environment than cattle as their production requires less land and water, and generates less greenhouse gases [2]. According to the UN, the global population will reach approximately 9.7 billion people by 2050 [3]. This means that food production will need to increase to meet the higher food demand, while the available arable land area will be limited.

On the African continent, many insects are important sources of nutrition, with their consumption increasing usually in the rainy season, when the availability of game and fish decreases. In Asian countries, entomophagy has changed because of population migration. More than 50 species of insects are eaten in South Asia (India, Pakistan, Sri Lanka), and 39 species in Papua New Guinea and the rest of the Pacific islands [4]. At the same time, consumers in the Western world are reluctant to consume insects, mainly as a result of prejudices. Their other concerns include the potential presence of allergens, pesticides, or heavy metals. In the coming years, however, the species of insects allowed for consumption by the new regulations are prognosed to become an increasingly important source of alternative proteins. This will contribute to the achievement of the goals of the "farm to table" strategy for a sustainable food system in the EU and in the world [5].

Numerous beneficial substances found in edible insects are potent to improve human health. These include steroidal materials, interferons, cordycepin, polysaccharides, microelements, chitin/chitosan, sex-attractive hormones, antimicrobial peptides, lecithin, and other nutrients. These specific functional substances may aid individuals in boosting immunity, battling tumours, controlling and regulating intestinal function, relieving fatigue, combating oxidation, preventing colds, promoting growth and development, and lowering blood sugar and blood pressure, among other advantages [5–8].

Edible insects are used as an ingredient in bakery products for different purposes, the majority of which are to increase protein and fibre levels in reformulated products or to provide protein support in gluten-free products. In wheat bread, the addition of insect powder can lead to increased crumb compression values (as a result of the modified gluten-network formation). Overall, the addition of insect powder (10%) has no detrimental effects on the technical properties of bread [9]. Driven by the necessity to alter the composition of bakery products, powdered insects have gained more attention as ingredients of bread, cookies, muffins, cakes, or extruded products [6]. Smarzyński et al. [7] observed an increase in the content of protein and essential amino acids, as well as fat in cookies made of wheat flour with a 2% cricket powder addition. These authors also reported higher levels of mineral compounds, such as Ca, Zn, Mn, Fe, K and Mg, which demonstrates a remarkable nutritional effect of insect powder addition even in a relatively modest quantity. Protein isolates from insects are low in fats and rich in essential amino acids. Both these properties make them suitable for improving the quality of enriched products. Luna et al. [8] produced protein hydrolysates from crickets (*Acheta domesticus*), which contained approximately 70% of crude protein, and applied it to tortillas and tortilla chips. The resulting products contained all essential amino acids, including lysine in a quantity that covered 40% of the recommended daily intake (2.1 g lysine per day for a 70 kg adult), and only 2.7% of fat. Sensory properties and neophobia are the main factors limiting the use of large quantities of insect flour in bakery products. In general, the inclusion of insect powder in bread results in a darkened colour of the product and a distinct aroma, which often negatively affect

its acceptability. Insect powder is gluten-free; hence, a partial replacement of wheat flour with it proportionally reduces the content of this protein fraction and directly affects the texture of the enriched food product. Decreases in hardness, elasticity, chewiness, and cohesion are reported as well, depending on the product [6]. Bakery goods are more likely than other food items to benefit from the addition of powdered insect ingredients, which could improve not only their nutritional value but also their technological and sensory qualities. Crickets, termites, grasshoppers, locusts, silkworm pupae, mealworms, and palm weevil larvae are among the regularly utilized edible insects, and they may often replace raw materials in concentrations between 5 and 25% of baked goods. Additionally, it has come to light that crackers filled with edible insects are preferred. Moreover, crackers had the highest values of sensory attributes, which did not differ substantially from those of the control sample. These high values are due to a high content of fat, which enhances their flavour and texture [10].

Food preservation procedures should be used to inhibit the development and/or inactivate pathogen and spoilage microorganisms to ensure food safety and extend the shelf life of edible insects. The most often used method of food preservation involves reducing the water content of foods (drying, freeze-drying), acidification, or thermal treatment (boiling, blanching, or sterilizing) [8].

This study investigated the effect of supplementing crackers with powders of edible insects (*Acheta domesticus*—cricket, *Locusta migratoria*—grasshopper, *Tenebrio molitor*—mealworm) on their physicochemical, nutritional, antioxidant, and sensory properties.

2. Materials and Methods

2.1. Chemicals

Ethanol, petroleum ether, Folin–Ciocalteu reagent, nitric acid, sulphuric acid, potassium hydroxide, sodium carbonate, sodium hydroxide, and acetylene were all purchased from Sigma-Aldrich (St. Louis, MO, USA) and CentralChem (Bratislava, Slovakia), respectively. All the chemicals were of analytical grade.

2.2. Preparation of Crackers

One of the contributors (Rajnoha) supplied an old family recipe that was used to make the crackers. Wheat was one of the ingredients purchased at a nearby market. One kind of insect powder was used to make each of the four types of crackers (Table 1). Powder was prepared at a laboratory using a laboratory mill (IKA M 20, Staufen, Germany) from whole edible insects purchased from a private company which produces certificated edible insects (WhizBE, Bratislava, Slovakia). Insect powder was applied in the amount of 5% of flour weight, which means 5 g per 100 g of flour. The produced dough was allowed to rest for 60 min at +4 °C after all ingredients were combined and kneaded (Diosna mixer SP 120, Mörfelden-Walldorf, Germany). A roller was used to roll the dough to a thickness of approximately 5 mm. The dough was moulded into the proper cracker shapes using hand cutting. Afterwards, the crackers were baked in an oven (MIWE condo, Arnstein, Germany) at 200 °C for 15 min. Then, they were cooled for 30 min, packed in polyethylene zipper resealable food bags and kept at +21 °C and 50% relative humidity until their physicochemical, nutritional, antioxidant, and sensory properties were examined.

Table 1. The recipe used in the preparation of the crackers.

Ingredients	Control	Cricket	Mealworm	Grasshopper
Wheat flour 00 Extra [g]	175	175	175	175
Emmental cheese [g]	100	100	100	100
Butter [g]	90	90	90	90
Egg [g]	60	60	60	60
Olive oil [g]	10	10	10	10

Table 1. *Cont.*

Ingredients	Control	Cricket	Mealworm	Grasshopper
Dry red paprika [g]	12	12	12	12
Cumin [g]	2	2	2	2
Cricket powder [g]	-	8.75	-	-
Mealworm powder [g]	-	-	8.75	-
Grasshopper powder [g]	-	-	-	8.75

2.3. Physicochemical and Nutritional Evaluation

2.3.1. Dry Matter, Ash, and Protein Contents

The AACC method 08-01 was used to determine the dry matter, ash, and crude protein contents [11]. The semi-micro-Kjeldahl method was applied to calculate the nitrogen content. A standard factor of 5.7 was used to convert nitrogen to protein.

According to manufacturer's guidelines, the Ancom XT15 Fat Extractor (Macedon, NY, USA) was used to measure the amount of fat in the sample. The sample (1.5 g, W1) was weighed into a special filter bag (XT4, Ancom, USA) and dried at 105 °C for three hours to remove moisture before the extraction.

Samples were placed in a desiccant pouch for 15 min, reweighed (W2), and then extracted with petroleum ether at 90 °C for 60 min. Following the procedure, the samples were taken out, dried at 105 °C for 30 min in an oven, put in a desiccant bag, and reweighed (W3). The following formula was used to compute the fat content (%): $[(W2 - W3)/W1] \times 100$.

2.3.2. Amino Acid Analysis

The manufacturer of the amino acid analyser (Ingos, Prague, Czech Republic) recommended using ion-exchange chromatography with a strong cation ion exchanger and a sodium-citrate elution buffer system, followed by post-column derivatization with ninhydrin and spectrophotometric detection, to determine the amino acid composition. The amino acid analyser was calibrated using a standard solution of amino acids. Tryptophan was not quantified since acid hydrolysis destroyed it. They were found in these forms because glutamine and asparagine transform into glutamic acid and aspartic acid, respectively.

2.3.3. Mineral-Compound Analysis

With a D2 lamp background correction system and an air-acetylene flame (air 13.5 L/min, acetylene 2.0 L/min; Varian, Ltd., Mulgrave, Australia), the Varian model AA 240 FS was used to analyse mineral compounds. The outcomes were compared to the multielementary GF AAS standard, CertiPUR® (Merck, Darmstadt, Germany). A 1:1 ratio of HNO3 and redistilled water was used to digest the sample. A closed-vessel high-pressure microwave digester (MARS X-press, Charlotte, NC, USA) was used to digest the samples for 55 min. The suspension was diluted to 50 mL with distilled water after cooling to room temperature and filtering with Munktell filter paper (grade 390.84 g/m, Baerenstein, Germany). Then, the sample extracts were subsequently analysed for the contents of Cd, Pb, Cu, Zn, Co, Cr, Ni, Mn, and Fe. The wavelengths at which the heavy metals were analysed following the calibration process were as follows: Cd—228.8 nm, Pb—217.0 nm, Cu—324.8 nm, Zn—213.9 nm, Co—240.7 nm, Cr—357.9 nm, Ni—232.0 nm, Mn—279.5 nm, Fe—241.8 nm.

2.3.4. Calorific Value Analysis

The calorific values of the samples were calculated using a bomb calorimeter IKA C 5000 (IKA Works, Wilmington, NC, USA). Since it is more suited for loose samples, the adiabatic approach was chosen for the measurement. The samples were put in the bomb calorimeter's crucible and electronically fired so they would burn in the presence of just pure oxygen. Using an external scale (Libra Axis AG1000C, Gdańsk, Poland), the samples were weighed; their masses ranged from 0.63 mg to 0.89 mg. The samples were ignited using cotton threads, and the quartz crucibles utilized were 20 mm in diameter and

20.5 mm in height. Heat was released during combustion, and the rise in temperature was monitored. The calorimeter's effective heat capacity of water was calibrated using dry benzoic acid.

2.4. Antioxidant Characteristics

2.4.1. Preparation of Extracts

A volume of 20 mL of 80% ethanol was used to extract one gram of a homogenised material (IKA, A10, Germany, Mesh 8) for two hours. The supernatant from centrifugation conducted at 3000×g (Himac CT 6E, Hitachi Ltd., Tokyo, Japan) for 20 min was used for total-polyphenol-content determination and DPPH assay.

2.4.2. DPPH—Antioxidant Activity

According to the steps outlined by Yen and Chen [12], 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay was used to determine the samples' capacity to eliminate free radicals. DPPH (0.012 g) was dissolved in 100 mL of ethanol, and 4 mL of the DPPH solution was added to the extracts (1 mL). The absorbance of the extracts was measured at 510 nm using a BioTek Microplate Reader (ELx800, Agilent Technologies, Santa Clara, CA, USA). Antioxidant activity of the samples was expressed as mg of Trolox equivalent antioxidant capacity (TEAC) per gram of dry matter.

2.4.3. Total Polyphenol Content

The total polyphenol content of the samples was determined spectrophotometrically using the Folin–Ciocalteu method, modified by Singleton et al. [13]. The Folin–Ciocalteu reagent (0.1 mL), 0.1 mL of the sample extract, and 1 mL of 20% sodium carbonate were combined. BioTek Microplate Reader (ELx800) was used to detect absorbance at 700 nm. The total content of polyphenols was expressed as mg of gallic acid equivalent (GAE) per dry matter.

2.5. Sensory Characteristics

A sensory panel of 25 evaluators, including 15 women and 10 men, aged 25 to 65, assessed the organoleptic qualities of the produced gingerbread crackers. The panel lists were asked to assess the overall acceptability, general appearance, taste, and aroma of the crackers. The samples were rated using a 9-point hedonic scale, with values ranging from 9 (very like) to 1 (strongly dislike).

2.6. Statistical Analysis

All analyses were performed in triplicate, and the findings are the averages with standard deviation of these duplicates. Using SAS 2009 software, the experimental data were subjected to analysis of variance (Duncan's test) at a 0.05 level of confidence [14].

3. Results and Discussion

3.1. Physicochemical and Nutritional Evaluation of the Prepared Crackers

The dry matter content of the tested samples ranged from 90.31% to 91.06% (Table 2). The tested crackers contained more than 80% of dry matter and less than 20% of water, which is typical of products with a long shelf-life. The content of fat ranged from 30.82% to 34.97% (Table 2). The addition of edible insect powder resulted in an increased fat content compared to the control sample. Fat is the second most abundant component of edible insects after proteins. It has been reported that quantities of polyunsaturated fatty acids found in the fatty acid profile of edible insects are proportional to those in fish and poultry.

Table 2. The total ash, crude protein, dry matter, and fat content and caloric value of analysed crackers.

Sample	Ash [%]	Crude Protein [%]	Dry Matter [%]	Fat Content [%]	Caloric Value [kcal/100 g]
Control	1.37 ± 0.05 ^{c}	14.83 ± 0.05 ^{d}	90.31 ± 0.02 ^{d}	30.82 ± 0.97 ^{c}	570.7 ± 0.58 ^{c}
MW crackers	1.56 ± 0.03 ^{a}	15.42 ± 0.04 ^{b}	90.83 ± 0.03 ^{b}	32.88 ± 0.11 ^{b}	579.1 ± 3.33 ^{b}
GS crackers	1.41 ± 0.02 ^{c}	15.23 ± 0.07 ^{c}	91.06 ± 0.01 ^{a}	34.97 ± 0.62 ^{a}	585.4 ± 3.12 ^{a}
CC crackers	1.48 ± 0.02 ^{b}	15.99 ± 0.03 ^{a}	90.55 ± 0.02 ^{c}	33.93 ± 0.02 ^{ab}	573.9 ± 1.19 ^{c}

Mean ± standard deviation; $^{a–d}$—different letters in a line indicate mean values that are statistically different from each other; MW—crackers with 5% addition of mealworm powder; GS—crackers with 5% addition of grasshopper powder; CC—crackers with 5% addition of cricket powder.

According to Imathiu [3], insects accumulate significantly lower levels of cholesterol compared to other animals. In a study by Mihaly Cozmuta et al. [15], linoleic acid was the major polyunsaturated fatty acid in the bread with cricket addition, while polyunsaturated fatty acids in these breads are correlated with lower oxidative stability. In a study by Kowalski et al. [16], oleic acid was found to be dominant in powders of mealworm, cricket and lesser mealworm (from 28.79% in cricket to 42.95% in mealworm). This was followed by palmitic acid (from 23.76% in lesser mealworm to 26.02% in Acheta domesticus). Small amounts of other polyunsaturated fatty acids, such as arachidonic acid (from 0.11% in cricket to 0.32% in Tenebrio molitor), were also determined. According to the same authors, the ratio of polyunsaturated to saturated fatty acids in the investigated insect powders was generally unfavourable, ranging from 0.59 (mealworm powder) to 0.89 (other edible insects). Moreover, edible insects contain low levels of omega-3 fatty acids. The crude protein content (Table 2) of the analysed samples ranged from 14.83 to 15.99%. All the enriched samples contained statistically higher amounts of crude protein, with the highest value determined in the crackers with cricket powder. The digestibility of cricket proteins ranged from 50.2% to 83.9% and was lower than that of eggs (95%), beef (98%), and cow milk (95%). In contrast, it was higher than that of some plant proteins, e.g., sorghum (46%), maize (73%), wheat (81%), and rice (66%) [17]. Edible insects are currently a promising source of protein for the food industry due to their nutritional value. It has been reported that protein levels vary within the same species by more than 50 percent depending on the stage of the life cycle, feed and other conditions. Protein levels fluctuate from 7 to 91 percent. Some sources have stated that insects need up to 10 times less feed than cattle to produce the same amount of protein. González et al. [18] substituted 5% of wheat flour with powdered black soldier fly, cricket, and mealworm, and investigated the chemical parameters of the mixture. The reported protein contents were 45.09 ± 0.82%, 56.58 ± 0.86%, and 48.82 ± 0.76%, respectively, and all were higher than that determined in the control sample that did not contain insect powder. Mihaly Cozmut et al. [15] analysed the crude protein content of white wheat bread enriched with 10% of cricket powder or 10% of mealworm powder. The control bread made using solely wheat flour had a protein content of 10.62 ± 0.53 g/100 g, whereas the values reported for the cricket and mealworm breads were 15.99 ± 1.01 g/100 g and 13.76 ± 0.42 g/100 g, respectively. Moreover, the reported levels of essential amino acids (EAAs) in wheat flour bread reached 43.07%, whereas the breads with cricket and mealworm showed higher values of 45.61% and 44.21%, respectively. On the other hand, some current reports have revealed that the 10% addition of insect powder, irrespective of the insect species used, does not impact the amino acid profile significantly [6].

In our study, the crackers with the addition of edible insect powders had higher contents of all the analysed amino acids compared to the control sample (Table 3).

Table 3. Amino acid composition of the analysed crackers.

Parameter [mg per g]	Control	MW Crackers	GS Crackers	CC Crackers
Aspartic acid (Asp)	9.65 ± 0.02 ^{d}	10.83 ± 0.06 ^{c}	11.11 ± 0.02 ^{a}	10.95 ± 0.07 ^{b}
Threonine (Thr)	5.05 ± 0.06 ^{b}	5.75 ± 0.04 ^{a}	5.67 ± 0.02 ^{a}	5.75 ± 0.05 ^{a}
Serine (Ser)	8.47 ± 0.03 ^{d}	9.29 ± 0.03 ^{a}	9.11 ± 0.02 ^{c}	9.17 ± 0.02 ^{b}
Glutamic acid (Glu)	41.83 ± 0.16 ^{b}	43.85 ± 1.01 ^{a}	41.98 ± 0.02 ^{b}	43.53 ± 0.09 ^{a}
Proline (Pro)	15.01 ± 0.04 ^{d}	17.35 ± 0.07 ^{b}	17.64 ± 0.07 ^{a}	15.51 ± 0.05 ^{c}
Glycine (Gly)	3.85 ± 0.03 ^{d}	4.49 ± 0.05 ^{a}	4.31 ± 0.02 ^{c}	4.43 ± 0.02 ^{b}
Alanine (Ala)	4.79 ± 0.15 ^{c}	5.73 ± 0.04 ^{b}	5.81 ± 0.05 ^{b}	6.06 ± 0.04 ^{a}
Valine (Val)	7.64 ± 0.07 ^{c}	8.08 ± 0.03 ^{b}	8.33 ± 0.04 ^{a}	8.41 ± 0.02 ^{a}
Isoleucine (Ile)	6.06 ± 0.06 ^{d}	6.64 ± 0.07 ^{c}	6.81 ± 0.05 ^{b}	7.12 ± 0.03 ^{a}
Leucine (Leu)	12.86 ± 0.18 ^{d}	13.84 ± 0.06 ^{c}	14.09 ± 0.04 ^{b}	14.53 ± 0.06 ^{a}
Tyrosine (Tyr)	8.42 ± 0.03 ^{c}	8.66 ± 0.01 ^{a}	8.53 ± 0.03 ^{b}	8.51 ± 0.01 ^{b}
Phenylalanine (Phe)	8.18 ± 0.04 ^{c}	8.26 ± 0.04 ^{b}	8.26 ± 0.04 ^{b}	8.57 ± 0.03 ^{a}
Histidine (His)	3.54 ± 0.02 ^{c}	3.86 ± 0.12 ^{a}	3.71 ± 0.03 ^{b}	3.92 ± 0.04 ^{a}
Lysine (Lys)	8.28 ± 0.03 ^{d}	8.81 ± 0.02 ^{b}	8.65 ± 0.03 ^{c}	8.99 ± 0.04 ^{a}
Arginine (Arg)	5.45 ± 0.12 ^{d}	5.65 ± 0.06 ^{c}	5.82 ± 0.06 ^{b}	6.09 ± 0.12 ^{a}

Mean ± standard deviation; $^{a–d}$—different letters in a line indicate mean values that are statistically different from each other; MW—crackers with 5% addition of mealworm powder; GS—crackers with 5% addition of grasshopper powder; CC—crackers with 5% addition of cricket powder.

The crackers with mealworm powder had the highest contents of threonine, serine, glycine, tyrosine, and histidine, whereas those with grasshopper powder had the highest contents of threonine, proline, and valine. The contents of threonine, alanine, valine, isoleucine, leucine, lysine, phenylalanine, tyrosine, and arginine were the highest in the crackers with cricket powder. Lysine is the most important of these amino acids, as cereals, which are the basic element of a human's diet, generally contain it in small quantities.

In Africa, where malnutrition is rampant, the consumption of crickets helps alleviate deficiencies in the required amino acids. Moreover, tubers of plants that are poor in lysine and leucine are a staple food for the people of Papua New Guinea. The resulting nutritional deficit can, therefore, be solved by consuming lysine-rich crickets. On the other hand, tubers are relatively rich in tryptophan and aromatic amino acids, which are present in small amounts in crickets [19]. Protein analysis of 100 types of edible insects showed that their essential amino acid contents varied between 46 and 96 g/100 g of total amino acids, which makes these insects a rich source of amino acids for human nutrition [20].

The ash content was the lowest in the control sample, while the highest in the sample with mealworm powder (Table 2). Insect powders can be used to enrich cereal products with selected mineral elements. Most edible insects have high phosphorus levels. Insects are also considered a good source of manganese, copper, magnesium, selenium, zinc, iron, and calcium. The low levels of sodium in edible insects make them suitable for people with high sodium sensitivity [3].

In our study, the addition of edible insects was confirmed to result in increased contents of iron, zinc, copper, and manganese in the crackers (Table 4).

All these minerals are necessary for normal body function. The crackers with the grasshopper addition had the highest contents of copper and chrome. They were, however, also determined to contain lead, which was absent in all the other cracker variants. The crackers with the cricket addition had the highest contents of iron, manganese, zinc, and cobalt. Cadmium was not detected in the samples, and the content of heavy metals was generally within the approved limits of the following legal regulations: Regulation no. 608/3/2004—100 of the Ministry of Agriculture and Ministry of Health of Slovak Republic dated 15 March 2004, which issues the Food Codex of the Slovak Republic, regulating contaminants in food, and Regulation no. 18558/2006—SL of the Ministry of Agriculture and Ministry of Health of Slovak Republic from 11 September 2006, which issues the Slovak Food Code of the Republic, regulating contaminants in foodstuffs [21]. Heavy metals, usually considered systemic toxicants, include lead, mercury, arsenic, and cadmium. They

exert a toxic effect upon exposure, even at low levels. It is known that the contamination of food with heavy metals causes adverse health effects, both acute and chronic, in humans and animals. Currently, there is limited knowledge about the safety of edible insects regarding heavy metals. Certain heavy metals that have been detected and/or quantified in some edible insects include cadmium, lead, and mercury. Two heavy metals of greatest concern are cadmium and arsenic because of their potential to accumulate in black soldier fly and mealworm, which are the two main species of insects considered for use in food and feed, especially in western countries [22]. Montowska et al. [23] investigated the content of mineral substances in three types of powder from cricket. The contents of the analysed mineral compounds in 100 g of products were as follows: Ca (139–218 mg), K (826–1224 mg), Mg (86–113 mg), Na (263–312 mg), Cu (2.33–4.51 mg), Fe (4.06–5.99 mg), Mn (4.1–12.5 mg), and Zn (12.8–21.8 mg). The authors concluded that the powders from cricket could become valuable food ingredients. The high content of mineral compounds found in cricket powder could make it an additive in products for coeliac patients.

Table 4. Mineral compound composition in the analysed crackers.

Parameter [mg per kg]	Control	MW Crackers	GS Crackers	CC Crackers
Copper	1.51 ± 0.01^{d}	1.66 ± 0.03^{c}	2.19 ± 0.04^{a}	2.13 ± 0.01^{b}
Manganese	2.51 ± 0.02^{c}	2.84 ± 0.15^{b}	2.71 ± 0.03^{b}	4.16 ± 0.05^{a}
Iron	11.29 ± 0.02^{b}	10.91 ± 0.01^{c}	10.08 ± 0.11^{d}	12.38 ± 0.05^{a}
Chrome	0.21 ± 0.02^{a}	0.09 ± 1.01^{b}	0.24 ± 0.01^{a}	0.08 ± 0.01^{b}
Nickel	0.29 ± 0.03^{a}	0.08 ± 0.01^{d}	0.22 ± 0.01^{b}	0.16 ± 0.01^{c}
Zinc	11.62 ± 0.08^{d}	12.71 ± 0.04^{c}	13.15 ± 0.07^{b}	14.03 ± 0.08^{a}
Cobalt	0.18 ± 0.01^{b}	0.15 ± 0.01^{c}	0.12 ± 0.01^{d}	0.31 ± 0.02^{a}
Lead	n.d.	n.d.	8.33 ± 0.04^{a}	n.d.
Cadmium	n.d.	n.d.	n.d.	n.d.

Mean ± standard deviation; $^{a–d}$—different letters in a line indicate mean values that are statistically different from each other; MW—crackers with 5% addition of mealworm powder; GS—crackers with 5% addition of grasshopper powder; CC—crackers with 5% addition of cricket powder; n.d.—not detected.

The calorific value of the crackers with edible insects was higher compared to that of the control sample. This is not surprising, as edible insects are rich in fat (Table 2). Consumers nowadays are very concerned about the energy supply in their diet, especially the young generation. The moderate consumption of crackers containing edible insects can enrich the human diet and provide both energy and biologically active compounds. The calorific value of cricket powders reported by Montowska et al. [23] ranged from 488.1 kcal/100 g to 524.1 kcal/100 g.

3.2. Antioxidant Characteristics

The antioxidant activity of the tested samples varied from 1.93 to 2.64 mg TEAC/g (Table 5) and was positively affected by insect-powder addition, as the control sample had the lowest value.

Table 5. The antioxidant activity and total polyphenol content of the prepared crackers.

Parameter	Control	MW Crackers	GS Crackers	CC Crackers
DPPH [mg TEAC/g]	1.93 ± 0.05^{b}	2.51 ± 0.03^{a}	2.64 ± 0.58^{a}	2.56 ± 0.03^{a}
TPC [mg GAE/g]	0.49 ± 0.02^{d}	0.78 ± 0.01^{a}	0.61 ± 0.02^{c}	0.71 ± 0.02^{b}

Mean ± standard deviation; $^{a–d}$—different letters in a line indicate mean values that are statistically different from each other; MW—crackers with 5% addition of mealworm powder; GS—crackers with 5% addition of grasshopper powder; CC—crackers with 5% addition of cricket powder; DPPH—2,2-difenyl-1-picrylhydrazyl; TPC—total polyphenol content; TEAC—Trolox equivalent antioxidant capacity; GAE—gallic acid equivalent.

Navarro del Hierro et al. [24] studied the antioxidant potential of insect extracts to inhibit DPPH•. All extracts exhibited antioxidant activity: most of them showed 80% inhibitory activity. In general, it appeared that the extracts from cricket were more effective

than those from mealworm, regardless of the extraction method and solvent used (average values around 72% and 57%, respectively). However, these differences were found to be insignificant. The antioxidant properties of muffins with insect powders were evaluated based on the determination of the total phenolic content and the ability to inhibit DPPH• and ABTS•+ in a study by Zielińska et al. [25]. The lowest content of total phenols was determined in the control muffin (6.04 mg GAE/100 g) and the highest one in the muffins with mealworm and tropical house cricket (351.05 and 515.76 mg GAE/100 g, respectively). In general, the total phenolic content increased with a higher percentage of insect powder content in the muffins. Insects are generally rich in a wide variety of vitamins with antioxidant activity, including riboflavin, biotin and pantothenic acid. Grasshoppers, beetles, and crickets are especially rich in folic acid. Although other types of vitamins occur in relatively low amounts, it is believed that the content of vitamins in edible insects can be influenced and/or controlled by handling feed [26].

The total polyphenol content in the prepared samples varied from 0.49 to 0.78 mg GAE/g (Table 5) and was positively influenced by insect meal addition, as the control sample showed the lowest value. The total polyphenol content varies widely in processed foods. It depends on the time and extent of exposure to heat, pH, phytochemical structure, and the presence of oxygen. These processing conditions either increase the extraction or cause the degradation of phenolic compounds in foodstuffs. Polyphenols are compounds that elicit several pharmacological benefits: their properties include anti-inflammatory, antibacterial, antiviral, anti-allergenic, vasodilating, and anti-cancer activities. These properties are due to their antioxidant activity [27]. Nino et al. [28] were the first to confirm the presence of phenolic substances in farmed crickets, indicating that crickets may be able to absorb or sequester phenolics from food. The following phenolic acids were found to be the major phenolic compounds present in cricket and its extracts: 4-hydroxybenzoic acid, p-coumaric acid, ferulic acid, and syringic acid. Furthermore, cricket extracts obtained using microwave-assisted extraction showed higher in vitro antioxidant activity compared to the extracts from plant material used as feed. Crickets are also known to contain flavonoids—quercetin-3-glucoside, quercetin-3-rutinoside, kaempferol-3-glucoside, daidzein, quercetin, naringenin and apigenin. Marín-Morales et al. [29] conducted a study to determine and compare the biological activities of extracts and hydrolysates obtained from edible grasshopper in the early and mature stages of life to evaluate their potential as a source of bioactive compounds. Enzymatic hydrolysis has been shown to be effective in releasing compounds with biological activity, as the hydrolysates showed higher activities than the non-hydrolysed samples. Flavonoids present in the samples of grasshopper in both the early and mature stages of life were luteolin, apigenin, quercetin, kaempferol, quercetin-3-glucoside, and kaempferol-3-O-glucoside. Ferulic acid, p-coumaric acid, quercetin, and kaempferol could be derived from the feed, which consisted mainly of corn leaves. On the other hand, non-dietary polyphenols, such as coumarin and catechol, may be present in the insect cuticle, due to the role of phenoloxidases in cuticle structure formation in a process called sclerotization.

3.3. Sensory Characteristic

When evaluating overall appearance (Table 6), the evaluators were asked to assign points to the crackers on a scale from 1 point (unsatisfactory and unbalanced appearance) to 9 points (desired, balanced, fully satisfactory appearance).

The sample with cricket powder addition received the best score compared to the other samples containing insect powder. When evaluating the aroma, the evaluators were asked to assign a score from the range of 1–9 to the samples, with 9 points indicating an excellent, balanced, and pleasant aroma. The best aroma was determined in the control sample, followed by the samples with grasshopper, mealworm, and cricket powders. Regarding taste, the control sample was evaluated as the best. It was followed by the samples with mealworm, grasshopper, and cricket powder addition. The control sample also scored the best result for overall acceptability, receiving 7.42 points (Table 5). Generally, the samples

with edible insect powder were evaluated as acceptable, but some evaluators felt a foreign taste and aroma which resembled those typical of fish or mushrooms, or bitterness. For some evaluators, the samples with cricket and grasshopper were less salty compared to the control sample. Adámek et al. [30] evaluated energy bars with cricket and mealworm, and the sensory analyses they conducted revealed that the respondents associated their tastes with already-known flavours (salty, sweet, bitter, fish, French fries, chicken, and mushrooms). The most common answer reported by the respondents was a salty taste, followed by a sweet taste. Unusual comparisons, such as pine seeds, were reported as well. A positive consumer attitude towards these energy bars was registered, indicating that Czech consumers accept edible insects in a suitable form of a novel food product. In contrast, the greatest disadvantage turned out to be the relatively high price of edible insects, which is going to be mirrored in the price of the final product [31]. Additionally, many European consumers have an aversion to eating insects, which poses risks for such products in the expected market success. One of the most intriguing areas for future research is the fact that consumers are more likely to accept food products containing insects than the actual bug itself [32]. Pascucci and de-Magistris showed that providing nutritional information on product packaging has a positive effect on consumers' willingness to purchase insect-based products [33].

Table 6. The sensory characteristics of analysed crackers.

Parameter [points]	Control	MW Crackers	GS Crackers	CC Crackers
Aroma	7.06 ± 0.06^{a}	6.05 ± 0.05^{c}	6.43 ± 0.06^{b}	5.61 ± 0.01^{d}
Taste	7.22 ± 0.02^{a}	6.31 ± 0.09^{b}	6.22 ± 0.02^{bc}	6.21 ± 0.01^{c}
General appearance	7.62 ± 0.02^{a}	6.64 ± 0.64^{b}	7.62 ± 0.02^{a}	8.22 ± 0.11^{a}
Overall acceptability	7.42 ± 0.03^{a}	6.74 ± 0.01^{c}	6.91 ± 0.02^{b}	6.74 ± 0.02^{c}

Mean ± standard deviation; $^{a–d}$—different letters in a line indicate mean values that are statistically different from each other; MW—crackers with 5% addition of mealworm powder; GS—crackers with 5% addition of grasshopper powder; CC—crackers with 5% addition of cricket powder.

4. Conclusions

Edible insects are a suitable ingredient for enriched cereal products such as crackers. This raw material is rich in proteins, with a very good essential amino acid profile, and mineral compounds such as iron, manganese, and zinc. Based on our study results, it may be concluded that the addition of edible insects to crackers in an amount of 5% improved their nutritional profile compared to the control sample. Results have also shown that the samples with insect powder addition had higher contents of dry matter, crude protein, fat, and all identified amino acids compared to the control sample. The sample with grasshopper powder exhibited the highest antioxidant activity, whereas the sample with mealworm addition had the greatest content of total polyphenols. The addition of insects, specifically cricket powder, had a positive impact on the sample's mineral content, particularly zinc and iron. Therefore, future study on entomophagy should focus on enhancing marketing techniques to make sure that insects and insect-based goods become more attractive. An effective communication approach could increase access to insects and lessen the unfamiliarity, inappropriateness, and revulsion of future generations, which are the main factors in today's lack of acceptance of insects.

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