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THE EFFECT OF THE CRICKET POWDER ADDITION ON THE CHEMICAL COMPOSITION OF PORK SAUSAGES

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ABSTRACT

This study investigated the addition of cricket powder to pork sausages and its impact on the chemical composition, amino acid, and fatty acid profiles. Three experimental groups were prepared with different concentrations of cricket powder: a control group without the addition of cricket powder, E1 with the addition of 2% cricket powder, and E2 with the addition of 4% cricket powder. The experimental groups with cricket powder addition had higher water and protein content than the control group, but lower fat content and no significant change in cholesterol content. The most abundant amino acids were Lys, Leu, and Arg in the experimental groups with the addition of cricket powder. Among fatty acids, the highest representation was oleic acid, palmitic acid, and stearic acid. The experimental pork sausages contained more unsaturated fatty acids than saturated fatty acids, and the major fatty acids in all treatments were monounsaturated fatty acids (MUFA), with predominant oleic acid. The addition of cricket powder did not affect ($p \geq 0.05$) the chemical composition or the profiles of amino acids and fatty acids in pork sausages.

Keywords: cricket powder, pork sausages, chemical composition, amino acid, fatty acid

INTRODUCTION

The growing interest in alternative protein sources, including edible insects, is driven by environmental sustainability, nutritional benefits, and increasing global food security concerns. The food industry and scientific communities are actively exploring innovative ways to incorporate alternative proteins into meat products to address the challenges posed by traditional livestock farming practices. Insects are emerging as a promising protein source because of their high nutritional value, efficient feed conversion, and lower environmental footprint compared to conventional livestock (**van Huis *et al*., 2013**). The environmental impact of conventional livestock farming is significant, contributing to greenhouse gas emissions, deforestation, and excessive water consumption (**FAO, 2019**). In contrast, insect farming requires considerably fewer resources, produces lower levels of carbon dioxide and methane, and utilizes agricultural byproducts and organic waste as feed (**Oonincx & de Boer, 2012**). As the global population is projected to reach 9.7 billion by 2050, sustainable protein production methods, such as edible insects, are essential for ensuring long-term food security (**United Nations, 2019**).
In 2021, the European Food Safety Authority (EFSA) published a positive risk assessment of an 'insect-based food' application for the consumption of certain insect species. Under the Novel Food Regulation (European Union [EU] Reg 2015/2283), novel foods that include some specific insect species (namely *Acheta domesticus*, *Tenebrio molitor* larva, *Locusta migratoria*, and *Alphitobius diaperinus*) have been currently authorised. This critical and required step in the EU and other countries worldwide allowed the first food products containing insects to appear in the market (**Lähteenmäki-Uutela *et al*., 2021**). These products are often marketed as sustainable and environmentally friendly alternatives to traditional foods.
Edible insects provide a high-quality protein profile comparable to traditional meat sources, and also contain polyunsaturated fatty acids, minerals such as iron and zinc, vitamins B and E, and bioactive substances, making them an attractive supplement for enhancing the nutritional profiles of various food products and contributing to improved human health (**Paoletti *et al*., 2003; Banjo, Lawal & Songonuga, 2006; Cu, Co & La, 2012; Ntukuyoh *et al*., 2012; Kinyuru *et al*., 2013; De Castro *et al*., 2018; van der Klerx, 2018; Vivar-Vera *et al*., 2018**). As consumers increasingly choose ready-to-eat foods, the processing of meat into products has become one of the most commercially significant food sectors worldwide (**Mehta *et al*., 2013**).
Recent studies have focused on incorporating insect-derived ingredients, such as cricket powder or protein extracts, into meat products, such as sausages, burgers, and patties, to improve their nutritional and functional properties (**Bukkens & Paoletti, 2005; Payne *et al*., 2016; Kim *et al*., 2019**). Cricket powder improves meat texture, moisture retention, and protein quality while reducing reliance on conventional meat sources. Researchers have been investigating optimal processing methods, including drying, milling, and fermentation, to enhance the sensory acceptability of insect-based meat products (**Caparros Megido *et al*., 2013; Yi *et al*., 2013; Jansson & Berggren, 2015; Tan *et al*., 2016**). Despite some cultural resistance, consumer acceptance studies suggest that familiarity and proper marketing strategies can improve the perception of insect-based food (**Gmuer *et al*., 2016**). Insects are considered a sustainable and nutritious source of protein; however, their consumption may be associated with several risks, such as allergies (**Abdelmoteleb *et al*., 2018; Hall & Liceaga, 2021**), toxins, heavy metals, pesticides (**Poma *et al*., 2017; van der Fels-Klerx *et al*., 2018; van Huis, 2020**), and microbiological risks (**Garofalo *et al*., 2019**). It is important to address these risks through proper regulation, hygiene standards, and education to ensure the safe and sustainable consumption of insects as a food source (**Kour, Balwan & Kour, 2024**).
Although the chemical composition and nutritional value of some edible insects have been established (**Kinyuru *et al*., 2013; Payne *et al*., 2016; Pilco-Romero *et al*., 2023; Siddiqui *et al*., 2024a; Siddiqui *et al*., 2024b**), little is known about the nutritional value of meat products that include edible insects. An important part of the quality assessment of innovative insect-supplemented food types is the evaluation of sensory properties and overall acceptability, in addition to assessing their nutritional quality (**Pavelková, Haščík & Čech, 2022; Lemke *et al*., 2023; Lemke *et al*., 2024**).
Based on these considerations, this study hypothesizes that incorporating edible insect powder into conventional meat products will improve their chemical and nutritional profiles, while potentially modifying proximate components (moisture, protein, fat, and cholesterol), leading to improved nutritional value. Therefore, this study aimed to evaluate the effect of adding cricket powder as an alternative protein source on the basic chemical composition and amino acid and fatty acid profiles of pork sausages.

MATERIAL AND METHODS

Experimental design

For evaluation purposes, we prepared pork sausages with the addition of cricket powder (*Acheta domesticus*) for 2 and 4% *Acheta domesticus* cricket powder per 1 kg of meat. A variant was made without the addition of powder, which served as a control (C). Then, samples of the experiment with 2% addition of cricket powder (E1) and 4% addition of cricket powder (E2) to the meat part were prepared. The produced pork sausages were then packed into artificial casings, smoked, and heat-treated (the temperature in the product core reached 70 °C and persisted for 10 min). After production, the pork sausages were stored in a refrigerator at a

temperature–2-4 °C until evaluation. A total of 180 pork sausages (n = 60 pcs for one group) were produced in three experiments.
Cricket powder made from domestic crickets (*Acheta domesticus*) was purchased online from SENS Food Ltd., a cricket farm based in London. The nutritional composition of the cricket powder per 100 g of the product (**Table 1**).

Table 1 Nutritional composition of cricket powder per 100 g of product (SENS Food Ltd., cricket farm in London)

Energy	440 kcal (1841 kJ)
Carbohydrates	4 g
Fats	17.8 g
Proteins	66 g
Vitamin B_{12}	23 µg
Ca	433 mg
Fe	168 mg
Na	17 mg

The production of pork sausages took place in the premises of the Institute of Food Sciences, SUA Nitra. For production, we used 4.5 kg of pork shoulder and 4.5 kg of pork. The raw materials were first cut into smaller parts, ground, and divided into three parts of 3 kg each. Appropriate spices and water in the form of flake ice were added to the raw material prepared in this way and ingredients according to the recipe.

The following ingredients were used to prepare pork sausages for 3 kg of meat:

- nitrite salting mixture 60 g,
- ground black pepper 4.5 g,
- ground sweet pepper 6 g,
- ground hot pepper 6 g,
- nutmeg 1 g,
- garlic 3 g,
- breeze 24 g.

Chemical composition

The elemental chemical composition of the pork sausage samples (water, crude protein, crude fat, and cholesterol content) was analysed using an INFRATEC 1265 device (Germany), which operates in transmittance mode from 850 to 1050 nm at 2 nm intervals. The homogenized samples (50 g) were placed in a glass cup (90 × 90 × 15 mm) and scanned in duplicate. The spectrum of each sample was the average of five scan locations and was recorded as log 1/*T* (*where T is* the transmittance). The results are expressed as g.100 g^{-1}. All the determinations were performed in triplicate.

Amino acid composition

The content of amino acids was determined following acid hydrolysis in 6 N HCl at 110 °C for 24 h using the Automatic Amino acid Analyzer AAA 400 (Ingos a.s., Prague, Czech Republic), based on the colour-forming reaction of AA with the oxidative agent ninhydrin according to procedures used by **Straková *et al.* (2015).** The resulting values of AAs were recalculated to 100 % dry matter and expressed as g AA content per 100 g muscle. The determinations were performed in duplicates.

Fatty acid composition

The total fat content was quantified by Soxhlet extraction with petroleum ether, following the procedure described in ISO 12,966–2:2017: preparation of methyl esters of fatty acids, animal and vegetable fats, and oils. Gas chromatography of fatty acid methyl esters was used to analyse the individual profiles, as suggested by **Bobková *et al*. (2022).**
GC-FID was performed using an Agilent 6890 GC with a flame ionization detector (FID), and an analytical column: 60 m × 250 µm × 0.15 µm DB-23 (Agilent 122–2361) was used. The experimental conditions were as follows: injector temperature: 250 °C; injected volume: 1 µL; dividing ratio: 1/10; carrier gas: helium; head pressure: 238.96 kPa (2.225 mL/min); temperature program: 50 °C for 1 min, 25 °C/min until the system reached 175 °C, then 2 °C/min to 230 °C; detector temperature: 280 °C; gas detector: hydrogen: 35 mL/min, air: 350 mL/min, nitrogen; make-up gas: 30 mL/min.
The quality indicator was the elution time of separated analytes. The chromatograms of the samples were compared with those of the 42-component standard FAME mix (10 mg/mL) in methylene chloride containing C4-C24 FAME (2–4 % relative concentration), manufacturer Supelco, catalog number 47,885-U chromatography (Sigma-Aldrich, Steinheim, Germany). The samples were analysed in triplicate.

Statistical analysis

All analyses were performed in triplicate unless otherwise indicated. Results are reported as mean ± standard deviation of measurements. Data were analysed using one-way ANOVA analysis of variance, followed by Tukey's post hoc test at a significance level of $p \leq 0.05$ to test for differences between mean values. Data were analyses using XLSTAT software (version 2018.5.52280, Addinsoft, New York).

RESULTS AND DISCUSSION

The basic chemical composition of pork sausages without (C) and with the addition of cricket powder (E1, E2) is shown in **Table 2.**
The water and crude protein contents of the pork sausages with added cricket powder were higher than those of the control and increased with increasing cricket powder concentration. The crude fat content of the pork sausages with cricket powder was the highest in the control group and decreased with increasing cricket powder concentrations. The cholesterol content of pork sausage ranged from 1.22 %.100 g^{-1} (C) to 1.13 %.100 g^{-1} (E1).
Based on the statistical analysis (ANOVA and Tukey's post hoc test), we can conclude that no statistically significant differences were found between the studied groups (C, E1, and E2) in any of the analysed variables, namely, water, protein, fat, and cholesterol content ($p > 0.05$). Although the average values of individual indicators differed slightly between the groups (e.g., higher average water and protein content in groups E1 and E2, or higher fat content in the control group), these differences did not exceed the threshold of statistical significance. The coefficient of determination (R^2) showed that the most variability between the groups was explained in the case of protein (44%) and water (35%); however, even in these cases, the significance of the differences was not confirmed.
Han *et al.* (2023), who studied the effect of adding cricket flour (1%; 2.5%; 5%) to hybrid pork sausages, reported that with increasing additions of cricket powder, the moisture content decreased from 68.7% to 65.8%, whereas the protein content increased from 7.1% to 9.4%. Comparable results were reported by **Kovál *et al.* (2024)**, who evaluated sausages with the addition of 3, 6, and 12 % of cricket powder. **Ho *et al*. (2022)** mentioned the sausage with cricket powder (10%) was significantly lower ($p \leq 0.05$) in moisture and crude fat content (54.88% and 42.52%, respectively) than the control (59.77% and 48.61%, respectively), however, there was no change in protein content. They also reported that the lower moisture content of the cricket powder sausages may have been due to the replacement of lean meat with cricket powder, which has a lower moisture content. Compared to our study, other studies have reported that replacing 10% of pork with mealworm larvae, silkworm pupae, or cricket flour decreased the moisture content and increased the protein content, but did not change the fat content of cooked sausages **(Kim *et al*., 2016; Kim *et al*., 2017)**. Similar findings were reported in their work by **Cavalheiro *et al*. (2023)**, who investigated sausages with the addition of cricket flour at concentrations of 2.5%, 5%, and 7.5% as a meat substitute.
The chemical composition of meat products using insect powder as an addition or substitute is also largely influenced by the chemical composition of the insect, which depends on the breeding conditions, type of feed, developmental stage, environmental conditions, and processing technology. **(Rumpold & Schlüter, 2013; Adámková *et al*., 2017; Akullo *et al*., 2018; Kim *et al*., 2019).** Lipid content varies based on the developmental stage, but generally, pupae and larvae tend to have higher lipid content than their adult counterparts **(van Huis *et al*., 2013).**
Cricket powder (*Acheta domesticus*), being of animal origin, naturally contains cholesterol; the body of adult crickets contains 98 mg.100 g^{-1} of cholesterol **(Orkusz, 2021),** which may explain the slight increase in cholesterol levels observed in the sausage samples enriched with insect powder (0.13% and 0.14%) compared to the control group (0.12%). Although these differences were not statistically significant ($p > 0.05$), they were likely attributable to the endogenous cholesterol present in the insect biomass. On the other hand, e.g. **Jankauskienė *et al.* (2023)** found a reduction in cholesterol content after the incorporation of mealworm larvae into traditional sausages.
It is well established in the literature that insects contain chitin, a structural polysaccharide found in their exoskeleton, which can bind bile acids and influence lipid metabolism, potentially lowering serum cholesterol. However, in this study, chitin was neither quantified nor specifically analysed; therefore, this hypothesis cannot be confirmed. The potential positive effects of chitin on lipid profiles remain subjects for future investigations. Despite a slight increase in cholesterol, the overall levels remained low and did not pose a nutritional concern. Moderate improvements in protein content and unsaturated fatty acid profiles support the use of cricket powder in developing nutritionally enriched meat products.

Table 2 Chemical composition of pork sausages with the cricket powder addition (%.100 g^{-1})

Parameter/ Group	C	E1	E2	*p-value*	R^2
Water	62.11±0.13	64.35±0.10	65.03±0.11	0.279	0.346
Total Protein	19.49±0.07	20.58±0.04	20.74±0.06	0.173	0.443
Crude Fat	15.43±0.42	14.12±0.41	13.62±0.42	0.414	0.255
Cholesterol	0.12±0.05	0.13±0.04	0.14±0.04	0.429	0.246

Notes: Values are given as mean±SD (standard deviation); R^2 = coefficient of determination; C = control group without cricket powder addition; E1- pork sausages with 2% cricket powder addition; E2 – pork sausages with 4% cricket powder addition.

The composition of the AA in the pork sausages is shown in **Table 3**. Essential amino acids play crucial roles in various metabolic and physiological processes **(Walther & Sieber, 2011)**. Most edible insects can meet energy and protein requirements (**FAO, WHO, 1973**) because they contain a high quantity of these nutrients compared to conventional meat sources. For instance, 100 g of house crickets (*Acheta domesticus*) can provide 120% of the RDI for protein and 446 Kcal of energy compared to 44% protein and 122 Kcal from 100 g of beef and 32% of protein and 167 Kcal from 100 g of chicken (**Bawa *et al.*, 2020**). Histidine, isoleucine, leucine, lysine, threonine, tryptophan, and valine are essential amino acids found in cricket protein. These amino acids are necessary for the body, and cricket protein contains enough to meet or exceed the recommended intake for adults (**Raheem *et al.*, 2019**). **Cavalheiro *et al.* (2023)** in their study stated as the most abundant essential amino acids in cricket flour leucine (45.19 g.100 g^{-1}), lysine (36.72 g.100 g^{-1}), valine (30.63 g.100 g^{-1}), and phenylalanine (28.62 g.100 g^{-1}). Amino acids are not only the major nutritional components of frankfurters, but they are also involved in the taste and flavour of meat products **(Sforza *et al.*, 2006)**.

In our experiment, the amino acid content increased with the addition of cricket powder; however, the addition of cricket flour had no impact on the amino acid content of the pork sausages. The most abundant amino acids were Lys (2.37–2.57 g.100 g^{-1}), Leu (2.11–2.30 g.100 g^{-1}), and Arg (1.73–1.90 g.100 g^{-1}). **Cavalheiro *et al.* (2023)** found similar results in their work, when the most valued amino acids were glutamate (23–26.44 mg.g^{-1}), aspartate (14.48–16.72 mg.g^{-1}), lysine (11.89–14.07 mg.g^{-1}), leucine (11.05–13.79 mg.g^{-1}), alanine (9.35–12.75 mg.g^{-1}) and arginine (9.35–12.23 mg.g^{-1}).

Although the results of ANOVA and post hoc Tukey HSD analysis did not show statistically significant differences (p>0.05) in the concentrations of essential amino acids between the control group and the samples with the addition of cricket powder (P1 and P2), from a biological and nutritional perspective, even these small changes can be considered potentially beneficial. The observed slight increase in the average values of some amino acids (e.g., lysine, isoleucine, and threonine) in the groups with cricket powder, although statistically insignificant, may indicate that cricket powder supplements the meat with other available amino acids, possibly improving the balance of the amino acid profile, which may be important in the assessment of the biological value of the protein. Cricket powder is naturally rich in essential amino acids, such as valine, leucine, isoleucine, lysine, and threonine, which are limiting factors in many plants and some animal foods. Even a small increase in the proportion of these foods can contribute to a more complete source of protein, especially if the product is intended for children, seniors, or athletes. The coefficient of determination (R²) for the individual groups was very low (0.008–0.099), indicating that the group classification (i.e., the level of cricket powder addition) explained only a small part of the variability in the amino acid content.

The method of production and the composition of the ingredients can significantly affect the amino acid profile of the produced pork sausages. Our results show that pork sausages with cricket powder supplements have favourable nutritional value and should be part of a healthy diet.

Cricket powder generally has a high protein content (60–70%) and a balanced profile of essential amino acids, including leucine, tryptophan, methionine, and lysine (**Rumpold & Schlüter, 2013; van Huis *et al.*, 2013**). Pork, while a useful source of protein, may have lower concentrations of certain essential amino acids than cricket powder. By completing the gaps in the amino acid spectrum, the proteins from cricket powder successfully complemented the proteins of pork meat when added to sausages.

Furthermore, these proteins and amino acids are concentrated when crickets are dried and ground into a powder. This implies that the amino acid content of sausage can be altered by adding even a small amount of cricket powder. The distinct structural characteristics of cricket proteins, such as their high percentage of short peptides and balanced distribution of hydrophobic and hydrophilic amino acids, may also impact the protein network inside the meat matrix, thereby improving its texture and nutritional qualities.

Furthermore, edible insects can be added to animal protein-based foods as substitutes or ingredients. Replacing 10% of lean meat with pre-treated mealworms and silkworms in emulsified sausage significantly increased its protein and mineral content (**Kim *et al.*, 2016**). Similarly, silkworm (*Bombyx mori*) pupae added to pork meat batter increased the protein content of the meat product (**Park *et al.*, 2017**). Thus, these studies indicate that the addition of insect flour can increase the protein content of various foods. However, the black soldier fly (*H. illucens*) has a lower protein content than pork; therefore, insect-based Vienna-style sausages have a lower protein content than pork-based sausages (**Bessa *et al.*, 2019**).

Table 3 Effect of cricket powder on pork sausage composition (g.100 g^{-1})

Parameter / Group	C	E1	E2	*p*-value	R^2
Thr	1.15±0.13	1.16±0.10	1.25±0.11	0.561	0.009
Val	1.03±0.07	1.04±0.08	1.13±0.09	0.343	0.090
Met	0.94±0.11	0.94±0.07	0.99±0.07	0.732	0.015
Ile	1.03±0.13	1.04±0.09	1.13±0.09	0.495	0.020
Leu	2.11±0.26	2.13±0.18	2.30±0.19	0.533	0.009
Phe	1.10±0.13	1.11±0.09	1.20±0.10	0.520	0.011
Lys	2.37±0.30	2.38±0.21	2.57±0.22	0.555	0.009
Cys	0.46±0.06	0.45±0.05	0.47±0.04	0.932	0.051
His	1.11±0.07	1.12±0.09	1.22±0.09	0.328	0.099
Arg	1.73±0.22	1.75±0.15	1.90±0.16	0.539	0.010

Notes: Values are given as mean±SD (standard deviation); R^2 = coefficient determination; C = control group without cricket powder addition; E1- pork sausages with 2% cricket powder addition; E2 – pork sausages with 4% cricket powder addition; Thr = threonine; Val = valine; Met = methionine; Ile = isoleucine; Leu = leucine; Phe = phenylalanine; Lys = lysine; Cys = cysteine; His = histidine; Arg = arginine.

Osimani *et al.* (2018), **Lucas-Gonzalez *et al.* (2019)**, and **Cavalheiro *et al.* (2023)** stated that the predominant fatty acids found in cricket flour were linoleic (C18:2n6), palmitic (C16:0), oleic (C18:1n9c), and stearic (C18:0) acids.

The profiles of fatty acids in the tested pork sausages are shown in **Table 4**. The results showed no statistically significant differences in the fatty acid concentrations among the groups (p>0.05). None of the ten monitored fatty acids showed a significant change due to the addition of cricket powder. Post-hoc Tukey HSD analysis confirmed these findings. The coefficient of determination (R²) for the groups ranged from 0.002 (linoleic acid, C18:2 n-6) to 0.507 (eicosapentaenoic acid, C20:5 n-3), indicating that group classification (i.e., level of cricket powder addition) explained various levels of the fraction of variability in fatty acid content. The highest representation was oleic acid (48.62 – C to 51.36 g .100 g^{-1} – E1), followed by palmitic acid (24.20 – E1 to 24.29 g.100 g^{-1} – E2) and stearic acid (11.12 – E2 to 11.23 g.100 g^{-1} – C). Regarding the fatty acid profiles, the pork sausages contained more unsaturated fatty acids than saturated fatty acids.

Humans are unable to produce omega-3 and omega-6 fatty acids, which is why they must be included in the diet (**Mahan, Escott-Stump, & Raymond, 2012**). Regarding the n-3 and n-6 contents, the content of n-6 was higher than of that n-3, and the addition of cricket powder exerted no significant effect (p≥0.05). The omega 6 to omega 3 fatty acids (n6/n3) ratio is another commonly used index for assessing healthy diets. Studies have suggested that a high n6/n3 ratio in diet is possibly linked to the development of a variety of physiological disorders (such as cancer, coronary heart disease etc.) (**Bophimai & Siri, 2010; Milićević *et al.*, 2014**). Artificial diets with high linoleic, α-linolenic, eicosapentaenoic, or docosahexaenoic acid content increased the content of these fatty acids in insects tenfold. To achieve the ω-6/ω-3 ratio required for human consumption, diverse diets with sources of ω-3 fatty acids and protein should be used when rearing edible insects. This suggests the potential role of optimizing the ω-6/ω-3 ratio to improve human nutrition through the production of edible insects with a designed nutritional content (**Severini *et al*., 2018**).

Table 4 Effect of cricket powder on fatty acid pork sausage composition (g.100 g^{-1})

Fatty acid / Group	C	E1	E2	*p*-value	R^2
Lauric (C12:0)	0.02±0.02	0.03±0.02	0.03±0.02	0.835	0.183
Myristic (C14:0)	1.26±0.02	1.26±0.01	1.29±0.03	0.276	0.252
Palmitic (C16:0)	24.26±0.15	24.20±0.09	24.29±0.10	0.606	0.322
Heptadecanoic (C17:0)	0.23±0.01	0.22±0.01	0.22±0.05	0.806	0.162
Stearic (C18:0)	11.23±0.04	11.16±0.13	11.12±0.25	0.715	0.086
Oleic (C18:1 cis)	48.62±1.89	51.36±2.19	50.44±3.30	0.451	0.142
Vaccenic (C18:1 trans-11)	4.43±0.02	4.43±0.07	4.49±0.09	0.511	0.136
Linoleic (C18:2 cis)	6.38±1.09	5.26±1.42	5.86±1.01	0.546	0.287
Linoleic (C18:2 n-6)	0.11±0.01	0.10±0.01	0.10±0.01	0.265	0.002
α-Linolenic (C18:3 n-3)	0.33±0.06	0.29±0.09	0.28±0.06	0.686	0.031
Eicosenoic (C20:1 n-9)	0.88±0.15	0.95±0.26	0.89±0.28	0.932	0.068
Arachidonic (C20:4 n-6)	1.01±0.07	0.92±0.08	0.97±0.28	0.807	0.124
Eicosapentaenoic (C20:5 n-3)	0.06±0.01	0.05±0.01	0.05±0.01	0.097	0.507
Docosapentaenoic (C22:5 n-3)	0.13±0.01	0.13±0.01	0.13±0.01	0.243	0.310
Docosahexaenoic (C22:6 n-3)	0.04±0.01	0.04±0.01	0.04±0.01	0.369	0.307
Omega 3	0.80±0.06	0.74±0.12	0.75±0.07	0.709	0.032
Omega 6	5.73±1.61	4.87±2.39	5.24±1.56	0.502	0.006
∑ SAFA	32.38±0.37	31.52±0.87	31.92±0.90	0.426	0.154
∑ MUFA	59.01±1.39	61.22±1.87	60.03±1.37	0.296	0.388
∑ PUFA	8.05±1.81	6.00±2.66	7.42±1.77	0.508	0.005

Notes: Values are given as mean±SD (standard deviation); R^2 = coefficient determination; C = control group without cricket powder addition; E1- pork sausages with 2% cricket powder addition; E2 – pork sausages with 4% cricket powder addition.

Monounsaturated fatty acids (MUFA) were the major fatty acids in all treatments (59.01–61.22 g.100 g^{-1} of the product), and the experimental samples showed higher values. Oleic acid (C18:1n9c) was the predominant MUFA. Among the SFA, which concentration ranged from 31.52 (E1) to 32.38 g.100 g^{-1} (C), palmitic and stearic acids were the majority in all groups, with concentrations of 24.20–24.29 and 11.12–11.23 g.100 g^{-1}, respectively. The content of polyunsaturated fatty acids ranged from 6.00 (E1) to 8.05 g.100 g^{-1} (C). Among PUFA, the highest concentration (5.26–6.38 g.100 g^{-1} – C) was found in linoleic acid. Similar findings were presented in their work by **Cavalheiro *et al*. (2023).**

The polyunsaturated fatty acid (PUFA)/saturated fatty acid (SAFA) ratio is one of the most significant markers of lipid composition in a healthy diet. A diet with a PUFA/SAFA ratio close to 1 is recommended. A high PUFA/SAFA ratio (≥3) in the diet may promote tumour formation, whereas a low PUFA/SAFA ratio (≤0.33) in the diet could be atherogenic (**Turley & Thompson, 2015**). Interestingly, some insects contain lipids with a PUFA/SAFA ratio (close to one, indicating the strong nutritional potential of their lipids. Edible insects are also a better source of polyunsaturated fatty acids (healthy fats) compared to conventional livestock such as chicken and cattle (**Finke, 2002; Tzompa-Sosa *et al*., 2014**). For example, house crickets, mealworms and black soldier flies contain 0.8-13%; 1.2-13% and 0.5-10% of omega 3 fatty acids, respectively. They are also rich in omega 6 fatty acids: 29%, 27% and 10% in house crickets, mealworms and black soldier flies, respectively. Additionally, the oleic acid content of most edible insects ranged from 12%-30% of the total fatty acid content (**Oonincx *et al*., 2019**). The fatty acids of insects are generally comparable to those of poultry and fish in their degree of saturation but contain more polyunsaturated fatty acids (PUFA) (**Dobermann, Swift & Field, 2017; Raheem *et al*., 2019**). The ratio of-6 and-3fatty acids of edible insects is mostly 5:1 to 5.7:1 (**Kinyuru *et al*., 2015; Adámková *et al*., 2017**), reducing proinflammatory profile, which contributes to the prevalence of atherosclerosis, obesity, and diabetes (**Simopoulos, 2016**).

Other authors, such **Cruz-López *et al*. (2022); Krawczyk, Fernández-López, & Zimoch-Korzycka (2024); Lemke *et al*. (2024)**, have also investigated changes in the nutritional composition of meat products with the addition of various types of edible insects.

In addition to the protein contribution, cricket powder also has a distinct fatty acid profile that influences the lipid composition of the final product. Studies have shown that insect lipids often contain a higher proportion of unsaturated fatty acids, including beneficial polyunsaturated fatty acids (PUFAs), compared to conventional pork fat (**Kolobe *et al*., 2023; Perez-Santaescolastica *et al*., 2023**). This shift is significant because unsaturated fatty acids are associated with improved cardiovascular health, while saturated fats—typically more abundant in pork—are linked to adverse health effects when consumed in excess. The addition of cricket powder, therefore, can lead to a decrease in the relative amount of saturated fats and an increase in unsaturated fats, contributing to a healthier lipid profile in the sausages. Moreover, the presence of specific fatty acids in cricket powder, such as linoleic and alpha-linolenic acids, further underscores its potential to modify and improve the overall fatty acid balance within the product (**van Huis *et al*., 2013**). This shift is especially beneficial from a cardiovascular health perspective, as diets richer in unsaturated fats are associated with reduced risks of heart disease (**Belluco *et al*., 2013**).

Collectively, these compositional changes enhanced protein quality through improved amino acid content and a more favourable fatty acid profile are directly related to the inherent nutritional characteristics of cricket powder. This ingredient not only boosts the nutritional value of pork sausages but also supports the development of more health-conscious and sustainable meat products.

Although this study primarily focused on the chemical, amino acid, and fatty acid composition of sausages enriched with cricket powder, sensory attributes such as taste, aroma, texture, and overall acceptability play a crucial role in the market success of novel food products. According to previous research **(Caparros Megido *et al*., 2013; Cavalheiro *et al*., 2023; Lemke *et al*., 2024)**, the inclusion of insect-derived ingredients can affect the sensory qualities of meat both positively and negatively.

Studies indicate that lower concentrations of insect powder (e.g., 2–4%) generally do not negatively impact sensory acceptability and may even enhance juiciness or umami flavour **(Kim *et al*., 2017; Ho *et al*., 2022)**. However, higher concentrations may lead to changes in colour, a bitter aftertaste, or a dry texture, potentially reducing consumer acceptance **(Tan *et al*., 2016)**. Although no sensory evaluation was conducted in our study, the relatively low levels of cricket powder used (2% and 4%) suggest that sensory changes would likely be minimal and acceptable to most consumers, as supported by existing literature, e.g. **Pavelková, Haščík & Čech (2022).**

CONCLUSION

The results of this study confirmed that the addition of cricket powder (Acheta domesticus) at levels of 2% and 4% to pork sausages led to slight changes in their chemical composition, specifically an increase in protein and moisture content, and a decrease in fat content compared to the control sample without insect powder. However, these differences were not statistically significant ($p \geq 0.05$). The amino acid profile indicated higher levels of essential amino acids such as lysine, leucine, and arginine in the enriched samples, suggesting a potentially beneficial nutritional effect, even though these changes were not statistically confirmed. Similarly, no significant differences were observed in the fatty acid composition, although sausages with cricket powder showed a higher proportion of monounsaturated fatty acids, particularly oleic acid, which may be favourable for cardiovascular health. Based on these findings, it can be concluded that enriching pork sausages with cricket powder is a technologically feasible strategy to improve their nutritional value without negatively affecting basic chemical parameters. This type of hybrid meat product represents a promising direction for the development of functional foods that may contribute to addressing current nutritional and environmental challenges.

For practical implementation, further research should include sensory evaluation, consumer acceptance testing, and a closer assessment of safety related to insect use in food (e.g., allergens and microbiological safety). In the context of sustainability and global food security, the integration of edible insects into food production offers an important step toward innovative, nutritionally valuable, and environmentally friendly solutions.

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