Research Paper

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Cricket powder (*Acheta domesticus*) as a lean pork meat replacer in cooked sausages

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The incorporation of insects in everyday foods is a developing area. Therefore, the aim of this study was to determine the optimal percent replacement (5.0, 7.5 or 10.0%) of lean pork meat with cricket power (CP) in cooked sausages. For this purpose, the quality and safety were evaluated through the following parameters: pH, moisture, water activity, TBA value, colour (L*, a*, b*), texture and sensory profile, microbiological status and microstructure during seven-day cold storage. The pH of cooked sausages with CP increased while the moisture decreased. At the end of cold storage TBA values of cooked sausages with CP were lower compared to the control. A dose dependent decrease in colour lightness (L*) and redness (a*) was observed after lean pork meat replacement in batters and cooked sausages. For both the texture profile analysis and sensory profile, the panel found an increase in the hardness and springiness of the cooked sausages with 7.5 and 10.0% CP. The microbiological status of the cooked sausages was not compromised by the addition of CP. Disruptions in the microstructure of both batters and cooked sausages were observed. Dose-depend size increase of fat globules and air bubbles in the batters with 7.5 and 10.0% replacement of lean pork meat was observed leading to their destabilization. Overall, the 5.0% replacement of lean pork meat with CP affects in most positive way all evaluated parameters of the cooked sausages. Higher percent replacement could be possible after evaluation of emulsion stability and gel formation of the insect-based hybrid meat products.

1. Introduction

1.1. History and future

Consumption of insects is a historically and geographically widespread phenomenon in Asian countries (Ho et al., 2022a). According to Regulation (EU) 2015/2283, insects intended for human consumption are considered "novel food" due to the lack of food history in the EU. In Europe, the house cricket (Acheta domescticus) was officially approved for usage in food products only in Switzerland (Federal Food Safety and Veterinary Office, 01 May 2017).

1.2. Physiology and rearing

The house cricket (*Acheta domesticus* - L. 1758, order Orthoptera, family Gryllidae) originates from South Asia. In the last decades, it had spread widely and turned into a cosmopolitan, omnivorous insect with potential for industrial rearing. Since they are cold-blooded, they require less energy to maintain ho-

meostasis which results in more efficient feed conversion (Dobermann et al., 2017). House crickets need four to 12 times less feed than ruminants and half that of chickens and pigs to produce the same amount of protein (Cavalheiro et al., 2023).

1.3. Nutritional composition – benefits and risks

The dried house crickets are highly nutritional, containing a large amount of unsaturated fatty acids, including linoleic and α-linolenic acids, all nine essential amino acids as well as micronutrients (Calcium, Potassium, Magnesium, Vitamin A, etc.) (Dobermann et al., 2017). No matter their high nutritional value, the addition of insects in everyday food must be labelled and bolded according to Regulation (EU) 1169/2011 as they are source of chitin (Han et al., 2023).

Insects belong to arthropods (Arthropoda), therefore consumers suffering from an allergy to crustaceans (Crustacea) may experience an allergic reaction after consumption (Ho et al., 2022b).

1.4. Consumers acceptance

Over the past decade, a number of studies have been conducted to assess the degree of acceptance of insects as food by consumers. Since the consumption of insects (Entomophagy) is not traditionally advocated in Western countries such studies contribute to consumer acceptance and the development of products with added insects (La Barrbera et al., 2020). In general, a large part of consumers feel an aversion to the consumption of whole insects. Whereas the growing demand is driven by consumer curiosity about their sensory characteristics (Kulma et al., 2023).

1.5. Potential incorporation

Adding insects to daily foods in the form of powders/flours is proving to be the most suitable option for Western consumers. From the literature review, we found a significant number of publications from around the world aiming to incorporate insect powders/flours into various foods. The cricket powder was used in various bakery products, such as sponge cakes (Vlahova-Vangelova et al., 2022) and pasta (Ho et al., 2022a). Different authors reported a possible formulation of new hybrid meat products with cricket powder. Some of them suggest adding the cricket powder directly to the meat products (Smarzyński et al., 2019; Vlahova-Vangelova et al., 2021), others test the possibility of replacing part of the meat (Cavalheiro et al., 2023; Han et al., 2023). Therefore, the aim of this study was to determine the optimal percent replacement (5.0, 7.5 or 10.0%) of lean pork meat with cricket power in cooked sausages. For this purpose, the quality and safety were evaluated through the following parameters: pH, moisture, water activity, TBA value, colour (L*, a*, b*), texture and sensory profile, microbiological status and microstructure.

Table 1. Formulations of the cooked sausages

Sample/ Ingredient	Control	CP1.5	CP2	CP3
Lean pork meat (g)	1800	1650	1575	1500
Pork bacon (g)	1200	1200	1200	1200
Cricket powder – CP (g)	-	52.00	78.00	102.00
Water (ml)	-	98.00	147.00	198.00
Flaky ice (g)	450.00	450.00	450.00	450.00
Table salt (g)	60.00	60.00	60.00	60.00
Sodium nitrite (g)	0.21	0.21	0.21	0.21
Sodium tripolyphosphate (g)	6.00	6.00	6.00	6.00
Total amount (g)	3516.21	3516.21	3516.21	3516.21
Lean meat replacement (%/ g)	-	5.00/ 150	7.50/ 225	10.00/ 300
CP in final product (%)	-	1.50	2.00	3.00

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2. Materials and Methods

2.1. Experimental design

For the production of the cooked sausages a chilled (48 h *post mortem*) lean pork meat (*M. semimebranosus, M. semitendinosus*), pork bacon (*M. pectoralis major*) and salting ingredients bought from the local and specialized merchants and cricket powder from Aceta domesticus (EntoSynergy Ltd., Bulgaria) were used (Table 1). The proximate composition of the cricket powder was: protein 58.10 (% DM), fat 14.43 (% DM), carbohydrates 12.90 (% DM), moisture 15.47 (%). Its pH was 6.83 and colour parameters were L* - 61.15; a* - 4.00 and b* - 17.74.

The chilled (0.0±0.5 °C) pork meat was grinded at 3 mm diameter mesh. The pork meat was finely chopped in a cutter machine (EMS Muller, MTK30, Saarbrucken west-Germany) with table salt, nitrite, tripolyphosphate and flaky ice. Upon achieving a homogenous batter, the cricket powder and respective amount of water based on the dry matter of the CP (85.43%) were added and mixed. The whole procedure for batter processing was repeated 4 times to obtain each of the 4 samples. One part of each batter was tested immediately to evaluate the influence of the "percent replacement of lean pork meat" factor. The second part was stuffed in polyamide casings. Sausages were steam boiled until a temperature of 72 °C in the centre was reached. The cooked sausages were stored at 0 – 4 °C for seven days without additional packing. The following analyses were carried out on the first and seventh days of cold storage.

2.2. pH determination

pH value was determined in triplicate using portable meat pH meter HI99163 (Hanna Instruments, USA) equipped with stainless steel probe for meat products (FC099). The pH meter was calibrated with 4.04 and 6.86 buffer solutions (Young et al., 2012).

2.3. Moisture and water activity (aW)

Moisture content was determined after drying at 104 °C until constant weight. The water activity was evaluated using Novasina AG CH-8853 (Zurich, Switzerland) at 20 °C (Vandeweyer et al., 2017).

2.4. Lipid oxidation

The secondary products of lipid peroxidation were determined by the 2-thiobarbituric acid assay as described by Botsoglou et al. (1994). Briefly, 10 grams sample is homogenized with 50 cm^3 0.9% NaCl for 3 min. A 50 cm^3 10% trichloroacetic acid is added to the solution to precipitate the extracted proteins. Solutions are filtrated and 4 cm^3 extract is mixed with 1% 2-thiobarbituric acid (freshly prepared). The mixture is heated at 70°C for 30 min. The absorbance of the solution is measured at 532 nm against black prepared with distilled water instead of extract. For this purpose, a dual beam UV-VIS spectrophotometer Camspec M550 (Spectronic CamSpec Ltd, United Kingdom) was used. The results are presented as mg MDA/ kg sample.

2.5. Instrumental colour determination

The CIELAB (L*; a*; b*) colour coordinates of the batter and the cross-cut surface of cooked sausages were determined as described by (Young et al., 2012) by colorimeter (Konica Minolta CR-410, Japan). Additionally, the total colour difference (ΔE) was calculated to compare the experimental samples (CP1.5; CP2 and CP3) to the control sample.

2.6. Texture profile analysis (TPA)

The texture profile was represented by the plastic strength (PS) or hardness, structural strength (SS) or cohesiveness and springiness or elasticity. All measurements were conducted using an OB-05 penetrometer (Labor, Hungary) following the detailed recommendations of Vlahova-Vangelova et al. (2021).

2.7. Sensory profile

Before sensory evaluation, the cooked sausages were left at room temperature for 20 min and sliced right before the serving. The sensory characteristics of cooked sausages, appearance, texture, taste, smell, and colour of the cross-cut surface were evaluated by a five-member panel group. A five-ball hedonic scale was used (Civille et al., 2015). The scores from 1 to 5 represent how much the panellist like the tested sample: 1 – dislike extremely; 2 – dislike slightly; 3 – neither like nor dislike; 4 – like slightly; 5 – like extremely.

2.8. Microbiological status

The suspensions and decimal dilutions of cooked sausages were done following ISO 6887-2:2017. Total viable count (TVC), Coliforms count, Enterobacteriaceae and Yeasts and Moulds count were evaluated according to the recommendations for surface planting and pour plate techniques (ISO 4833-1:2013/ Amd 1:2022; ISO 4833-2:2013/ Amd 1:2022).

2.9. Light microscopy

Sample cuts (2x2x1 cm) from the centre of cooked sausages and batter were placed in 10% formalin overnight to prefix the structure. Fixed samples were dehydrated using gradually increasing ethanol solutions (50, 70, 96 and absolute). Dehydrated samples were bleached using acetone then transferred in xylene for 12 h and embedded in paraffin. A 5 μm thick slice was cut from the paraffin block and stained with haematoxylin-eosin (Barbut et al. 2005). The observation was done using a light microscope (Olimpus BX-41TF, Japan) equipped with a digital camera (Olimpus SC30, Japan) at x100 magnification.

2.10. Statistical analyses

Results are presented as Means ± Standard Error of Means (SEM). Data for the batters were processed using a One-way ANOVA to evaluate the effect of percent replacement of lean pork meat with CP at P<0.05 level of significance (n=5). Two-way ANOVA with replications (Student's t-test) was performed to determine the effect of both factors (percent replacement of lean pork meat and storage time of cooked sausages) and their interaction at P<0.05 level of significance (n=5). The add-in Analysis ToolPak -VBA for Microsoft Excel 2016 software was used for both statistical analyses.

3. Results

3.1. Physical-chemical properties

The pH of the batter was significantly (P<0.05) lowered due to the replacement of the lean pork meat with CP in a dose-dependent manner (Table 2) despite the high pH value of the CP (6.83). After cooking all three samples with CP (CP1.5, CP2 and CP3) had higher (P<0.05) pH than the control. This trend was also observed after seven-day of cold storage despite the decreased values (P<0.05).

Regardless of the added water for a high dry matter of CP compensation, the moisture of the three batter samples (CP1.5, CP2 and CP3) decreased (P<0.05). The decrease in moisture content compared to the control was dose depend (Table 2). The established trend line was also observed in the cooked sausages. During the seven-day cold storage, the moisture decreased significantly (P<0.05) in all four samples.

Water activity (aW) of all cooked sausages was not affected (P>0.05) either by the replacement of lean pork meat with CP or the cold storage (Table 2).

Table 2. Physical-chemical properties of batters and cooked sausages during seven-day cold storage

Sample/ Parameter	Storage time (d)	Control	CP1.5	CP2	CP3
$pH_{(batter)}$ (-)	-	6.32 ± 0.03^{d}	6.19 ± 0.01^{c}	6.16 ± 0.01^{b}	6.10 ± 0.01^{a}
$pH_{(sausages)}$ (-)	1	$6.21\pm0.02^{a,y}$	$6.37\pm0.02^{b,y}$	$6.41\pm0.02^{b,y}$	$6.43\pm0.03^{b,y}$
$pH_{(sausages)}$ (-)	7	$6.14\pm0.02^{a,x}$	$6.21\pm0.02^{b,x}$	$6.21\pm0.02^{b,x}$	$6.21\pm0.03^{b,x}$
$Moisture_{(batter)}$ (%)	-	28.38 ± 0.03^{d}	27.87 ± 0.06^{c}	23.82 ± 0.04^{b}	17.29 ± 0.04^{a}
$Moisture_{(sausages)}$ (%)	1	$42.80\pm0.02^{d,y}$	$25.32\pm0.02^{c,y}$	$13.44\pm0.04^{b,x}$	$9.38\pm0.03^{a,x}$
$Moisture_{(sausages)}$ (%)	7	$11.80\pm1.47^{a,b,x}$	$11.35\pm0.82^{a,x}$	$13.40\pm0.04^{b,x}$	$14.90\pm0.48^{c,y}$
$a_{W(sausages)}$ (-)	1	$0.95\pm0.02^{a,x}$	$0.96\pm0.01^{a,x}$	$0.96\pm0.01^{a,x}$	$0.94\pm0.02^{a,x}$
$a_{W(sausages)}$ (-)	7	$0.95\pm0.03^{a,x}$	$0.95\pm0.02^{a,x}$	$0.95\pm0.03^{a,x}$	$0.94\pm0.01^{a,x}$

^{a,b,c,d} – superscripts show significant (P<0.05) differences between Means in the row

^{x,y} – superscripts show significant (P<0.05) differences between Means in the same column for each parameter

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The TBA values of the cooked sausages on day one of cold storage vary from 1.12 to 1.23 mg MDA/kg. The control had the highest values of 1.23±0.02 and the lowest was in sample CP3 (P<0.05). During seven-day cold storage, TBA values in all cooked sausages increased significantly (P<0.05). Most significant was in control – from 1.23 to 1.40 or about 12%. The three samples with the replacement of lean pork meat with CP had no significant difference in TBA values - from 1.25 to 1.27 mg MDA/kg.

3.2. Instrumental colour determination

The results for the lightness (L*) of the colour of batters and the cross-cut surface of the cooked sausages during the cold storage showed a significant (P<0.05) CP dose depending on the decrease in values (Table 3). A similar decrease was also evaluated for the redness (a*) of both batters and cooked sausages. The yellowness (b*) of the batter was the highest in the control and lowest in CP3 (P<0.05) despite of the high b* values of CP. As for the cooked sausages with the replacement of lean pork meat with CP (samples CP2 and CP3) b* values of the cross-cut surface were higher (P<0.05) than the control (Table 3, day one). The colour difference (ΔE) of all samples was from 2.52 to 6.33 meaning that even an inexperienced observer could spot the difference (Figure 1).

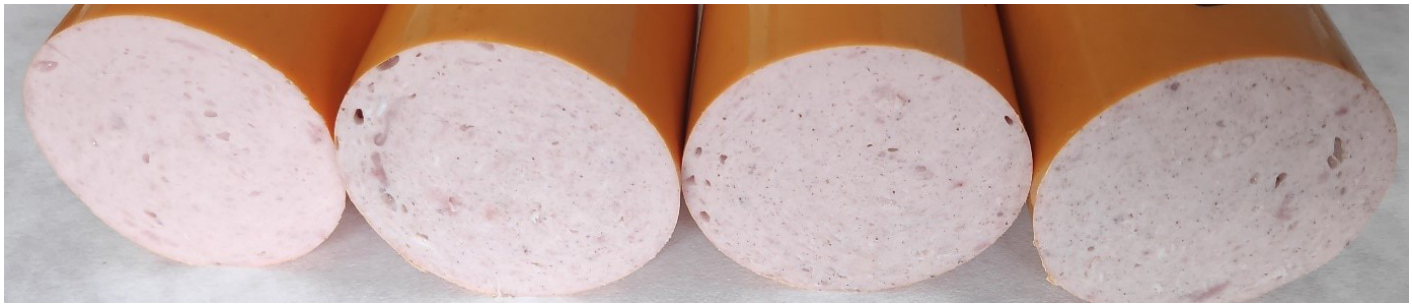

Figure 1. Photo of the cooked sausages – from left to right (Control; CP1.5; CP2; CP3)

Table 3. Colour of the batters and the cooked sausages during seven-day cold storage

Sample/ Parameter	Storage time (d)	Control	CP1.5	CP2	CP3
$L^*_{(batter)}$ (-)	-	63.59 ± 0.34^{c}	$63.10\pm0.25^{b,c}$	61.89 ± 0.13^{b}	60.62 ± 0.12^{a}
$L^*_{(sausages)}$ (-)	1	$65.29\pm0.29^{d,x}$	$63.52\pm0.10^{c,x}$	$62.72\pm0.60^{b,x}$	$61.67\pm0.11^{a,x}$
$L^*_{(sausages)}$ (-)	7	$65.61\pm0.04^{d,x}$	$63.74\pm0.11^{c,y}$	$63.13\pm0.09^{b,x}$	$61.84\pm0.15^{a,x}$
$a^*_{(batter)}$ (-)	-	7.86 ± 0.07^{d}	5.47 ± 0.03^{c}	5.30 ± 0.05^{b}	5.18 ± 0.04^{a}
$a^*_{(sausages)}$ (-)	1	$13.97\pm0.11^{d,y}$	$10.12\pm0.04^{c,x}$	$9.66\pm0.02^{b,x}$	$8.77\pm0.01^{a,x}$
$a^*_{(sausages)}$ (-)	7	$13.78\pm0.04^{d,x}$	$10.30\pm0.03^{c,y}$	$9.86\pm0.03^{b,y}$	$9.05\pm0.03^{a,y}$
$b^*_{(batter)}$ (-)	-	12.09 ± 0.15^{c}	11.43 ± 0.04^{b}	11.06 ± 0.09^{a}	11.17 ± 0.08^{a}
$b^*_{(sausages)}$ (-)	1	$8.18\pm0.14^{b,x}$	$7.86\pm0.05^{a,x}$	$8.34\pm0.02^{c,x}$	$8.77\pm0.03^{d,y}$
$b^*_{(sausages)}$ (-)	7	$8.16\pm0.09^{a,x}$	$8.06\pm0.02^{a,y}$	$8.32\pm0.02^{b,x}$	$8.31\pm0.03^{b,x}$
$\Delta E_{(batter)}$ (-)	-	-	2.52	3.24	4.10
$\Delta E_{(sausages)}$ (-)	1	-	4.25	5.79	6.33
$\Delta E_{(sausages)}$ (-)	7	-	3.95	4.63	6.05

^{a,b,c,d} – superscripts show significant (P<0.05) differences between Means in the same row.

^{x,y} – superscripts show significant (P<0.05) differences between Means in the same column for each parameter

3.3. Texture profile analysis (TPA)

The texture profile of all samples was significantly affected by the replacement of lean pork meat with CP. The highest value (P<0.05) for plastic strength (PS) was evaluated in batter CP3 (Table 4). After cooking and 24 h of cold storage PS values increased in all sausages due to the thermal denaturation of the proteins. Samples CP2 and CP3 were characterized by two-time higher PS than the control (P<0.05). After seven-day cold storage, the PS of all cooked sausages decrease significantly (P<0.05) but maintained the trend from the first day.

The structural strength (SS) of all three batters with CP (samples CP1.5, CP2 and CP3) was higher (P<0.05) that the control (Table 4). Similar results were observed for the cooked sausages on day one of cold storage. Opposite to the plastic, structural strength increased (P<0.05) during the seven-day of cold storage in samples CP2 and CP3.

On day one of the cold storage the highest values for the springiness of the cooked sausages were measured in sample CP3. It was 29.41% higher (P<0.05) than the control (Table 4) During seven-day cold storage the elasticity of all three samples with replacement of lean pork meat with CP increased significantly (P<0.05).

3.4. Sensory profile

The sensory panel awarded the highest scores to control and CP1.5 cooked sausages (Figure 2). The sausages CP2 had lower sensory scores due to the harder texture and darker colour of the cross-cut surface (Table 3, Figure 1). The cooked sausages produced with 10% replacement of lean pork meat with CP (CP3) had a hard, gummy texture, dark colour and uncharacteristic taste and smell.

3.5. Microbiological status

An increase (P<0.05) in total viable count (TVC) was evaluated on day one of sausages' cold storage which corresponded well with the increased percent of CP (Table 5). During the seven-day cold storage, TVC increased significantly (P<0.05) for all samples. The TVC of the control sausages remained the lowest (P<0.05). No coliforms were found at the time of the experiment.

The *Enterobacteriaceae* count in all tested sausages both on the first and seventh day of cold storage did not differ significantly (P>0.05). An increase (P<0.05) in yeast and mould count was observed during the seven-day cold storage in all sausages. The control and CP1.5 remained lower for yeast and mould count compared to CP2 and CP3 (P<0.05). Yeast and mould count was not affected (P>0.05) by the replacement of lean pork meat with CP on day one of the cold storage (Table 5).

Table 4. Texture profile of batter and cooked sausages during seven-day cold storage

Sample/ Parameter	Storage time (d)	Control	CP1.5	CP2	CP3
$PS^{1}_{(batter)}$ (g/cm²)	-	1.20 ± 0.03^{a}	1.08 ± 0.02^{a}	1.08 ± 0.02^{a}	1.56 ± 0.02^{b}
$PS_{(sausages)}$ (g/cm²)	1	$32.56\pm0.83^{a,y}$	$52.09\pm0.85^{b,y}$	$66.71\pm1.00^{c,y}$	$64.16\pm0.61^{c,y}$
$PS_{(sausages)}$ (g/cm²)	7	$24.48\pm0.55^{a,x}$	$29.31\pm0.51^{b,x}$	$35.99\pm0.55^{c,x}$	$38.78\pm0.62^{d,x}$
$SS^{2}_{(batter)}$ (g/cm²)	-	10.36 ± 0.47^{a}	11.72 ± 0.70^{b}	12.10 ± 0.61^{b}	11.63 ± 0.35^{b}
$SS_{(sausages)}$ (g/cm²)	1	$195.03\pm2.21^{a,x}$	$306.51\pm3.07^{b,y}$	$300.29\pm2.90^{b,x}$	$375.81\pm2.24^{c,x}$
$SS_{(sausages)}$ (g/cm²)	7	$189.20\pm1.62^{a,x}$	$229.39\pm2.29^{b,x}$	$513.60\pm3.45^{c,y}$	$590.49\pm2.78^{d,y}$
$Springiness_{(sausages)}$	1	$0.48\pm0.07^{a,x}$	$0.50\pm0.10^{a,x}$	$0.60\pm0.07^{a,b,x}$	$0.68\pm0.08^{b,x}$
$Springiness_{(sausages)}$	7	$0.44\pm0.07^{a,x}$	$0.99\pm0.07^{c,y}$	$0.77\pm0.05^{b,y}$	$0.99\pm0.06^{c,y}$

[1]Plastic strength; [2]Structural strength

^{a,b,c,d} – superscripts show significant (P<0.05) differences between Means in the same row.

^{x,y,z} – superscripts show significant (P<0.05) differences between Means in the same column for each parameter

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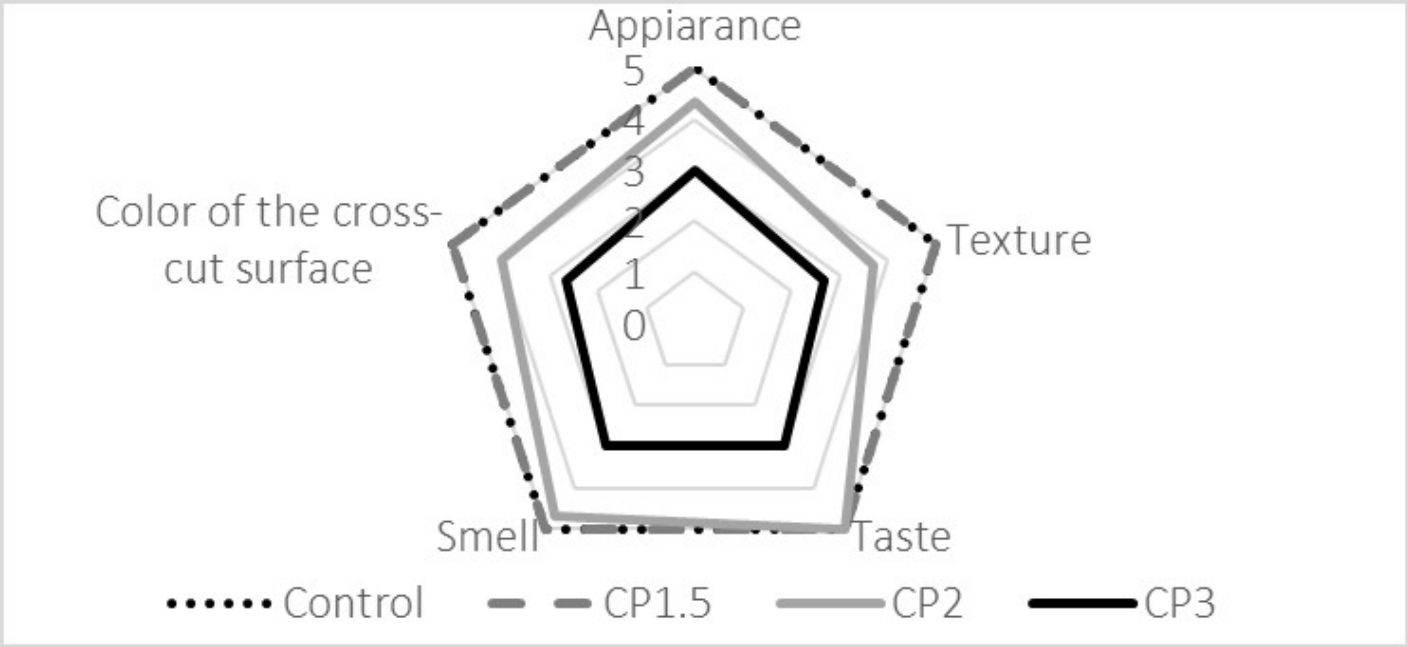

Figure 2. Sensory profile of cooked sausages at the first day of cold storage

Table 5. Microbiological status (lg CFU/g) of cooked sausages during seven-day cold storage

Sample/ Parameter	Storage time (d)	Control	CP1.5	CP2	CP3
TVC[1]	1	$3.00\pm0.07^{a,x}$	$3.30\pm0.09^{b,x}$	$3.60\pm0.05^{c,x}$	$3.78\pm0.06^{d,x}$
TVC	7	$3.78\pm0.09^{a,y}$	$4.60\pm0.07^{c,y}$	$4.30\pm0.11^{b,y}$	$4.30\pm0.10^{b,y}$
Coliforms	1	N.F.[2]	N.F.	N.F.	N.F.
Coliforms	7	N.F.	N.F.	N.F.	N.F.
Enterobacteriaceae	1	$5.49\pm0.39^{a,x}$	$5.58\pm0.43^{a,x}$	$5.43\pm0.48^{a,x}$	$5.58\pm0.46^{a,x}$
Enterobacteriaceae	7	$5.16\pm0.28^{a,x}$	$5.20\pm0.45^{a,x}$	$4.87\pm0.19^{a,x}$	$5.11\pm0.27^{a,x}$
Yeasts & Moulds	1	$3.30\pm0.15^{a,x}$	$3.83\pm0.62^{a,x}$	$3.59\pm0.64^{a,x}$	$4.00\pm0.64^{a,x}$
Yeasts & Moulds	7	$4.53\pm0.33^{a,y}$	$4.49\pm0.16^{a,y}$	$5.07\pm0.32^{b,y}$	$5.20\pm0.38^{b,y}$

[1]Total viable count; [2]Not found

[a,b,c,d] – superscripts show significant (P<0.05) differences between Means in the same row.

[x,y,z] – superscripts show significant (P<0.05) differences between Means in the same column for each parameter

3.6. Light microscopy

The microstructural images of the four investigated batters showed a matrix which consists of fat droplets wrapped in protein film, water and dispersed myofibrillar and connective tissue fragments (Figure 3). The formed fat globules in the control batter were properly distributed and approximately uniform in size. The shape and size of the globules were changed due to the addition of CP. This probably is the result of the rupture of the fat globules from the hard chitin fragments. Dose-depend size increase of fat globules and air bubbles in the batters CP2 and CP3 was observed leading to their destabilization.

After heat treatment, the microstructure of the con-

trol sausages was characterized by evenly distributed fat globules surrounded by a dense protein film and a strong gel matrix (Figure 4). The formed fat droplets and air bubbles were of regular shape and uniform distribution. Non-uniform distribution and formation of globules with different sizes and non-uniform

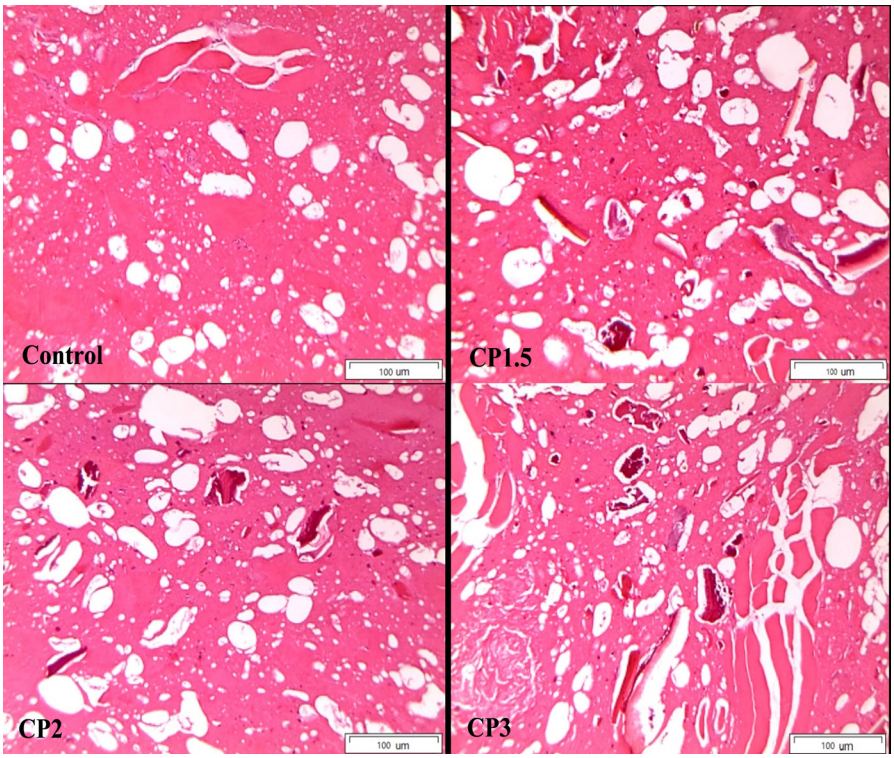

Figure 3. Microstructural images of batters stained with haematoxylin, x100 magnification

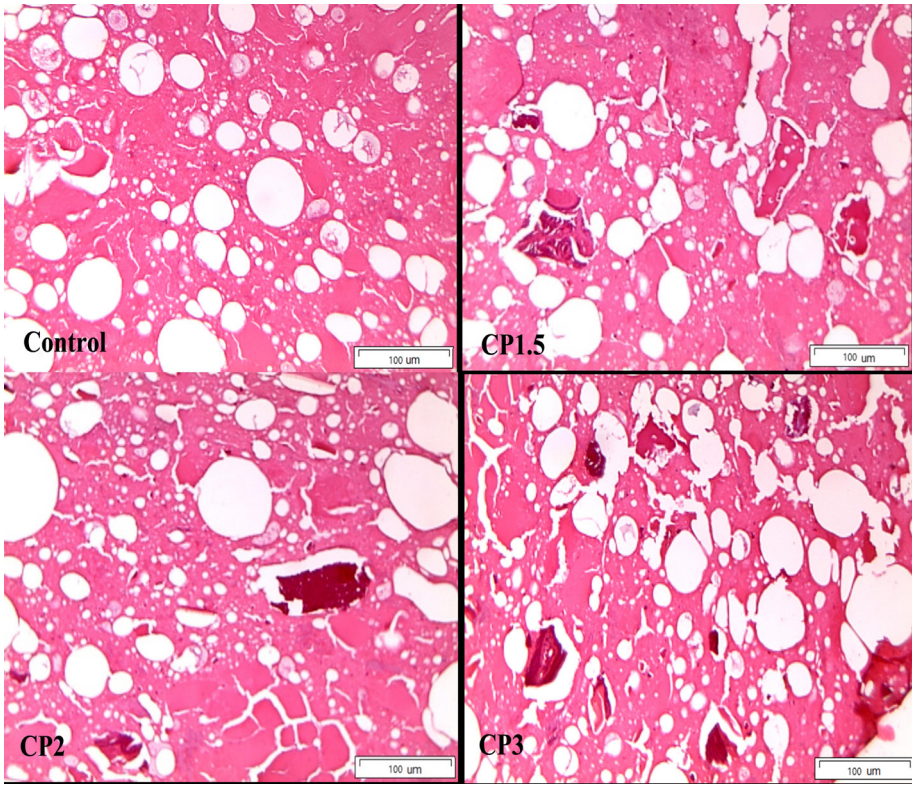

Figure 4. Microstructural images of cooked sausages stained with haematoxylin, x100 magnification

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gel matrices were observed for the cooked sausages with CP (samples CP1.5, CP2 and CP3) (Figure 4)
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4. Discussion

The evaluated results oppose to reported an increase of pH value in raw filling mass for hybrid poultry products with the addition of CP (Vlahova-Vangelova et al., 2021; Kolev et al., 2022). At the same time, Ho et al. (2022a) and Cavalheiro et al. (2023) report no difference in the pH of cooked pork sausages with/without cricket powder. Our results could be explained by the used salting ingredients (nitrites, polyphosphates) which changed the buffer capacity of the batter. The found decrease of moisture in the cooked sausages (CP1.5, CP2 and CP3) was in agreement with the pH values, suggesting that furthering out the isoelectric point of meat proteins (5.3- 5.6) lead to an increase of water binding capacity (Kim et al., 2017).

The large amount of fat in meat products and the applied heat treatment favour the development of chain-radical processes of lipid peroxidation. Inhibition of these processes is essential for the safety of meat products (Botsoglou et al., 1994). Chitin, which renders insect exoskeletons, is known to possess antioxidant properties (Lucas-González et al., 2019; Psarianos et al., 2022). The antioxidant potential of cricket flour is another positive feature when using it as an additive in the meat industry. Its presence in the produced sausages was probably the reason for the reduced accumulation of secondary products of lipid peroxidation.

The observed deviations of colour (L*, a*, b*) were significantly affected by the lean pork meat replacement with CP. The colour of the batters and the cross-cut surface of cooked sausages were influenced by the originally darker colour of the cricket powder. Our results confirm the reported decrease in the lightness of the cross-cut surface colour in other hybrid meat products (Kolev et al., 2022; Cavalheiro et al., 2023). Other authors suggest that carbohydrates in insect powder/flours could promote Maillard reactions or enzymatic browning (Lucas-González et al., 2019).

The significant decrease in the redness (a*) of cooked sausages with a 10% replacement of lean meat is in agreement with the reported results by Ho et al. (2022a). Smarzyński et al. (2019) observed a green shade of the colour of cricket powder which could explain the decreased redness and increased yellowness (b*).

The observed greater plastic and structural strength are in agreement with the evaluated decrease in moisture content, the reported decrease of firmness by Ho et al. (2022a) and the increased dry and firm texture by Vlahova-Vangelova et al. (2021). The increased springiness/elasticity of meat products with added insect powders was reported previously (Ho et al., 2022a). This could be explained by the fact that the CP is characterized by a good water binding capacity sufficient to bind the added water and some of the free water found in the meat matrix. Leading to an increase in the hardness and springiness/elasticity of meat products (Kim et al., 2017).

The instrumental colour determination and texture profile analyses were in agreement with the sensory panel scores. Panellists reported a linear increase of firmness, chewiness and dryness of the cooked sausages with the increase of lean pork meat replacement with cricket powder. Also, an alteration in taste and smell was reported in cooked sausages with 7.5 and 10.0% replacement of lean pork meat. Cavalheiro et al. (2023) also report a bitter taste and aftertaste of hybrid meat products with cricket powder. Those findings confirm previous statements about hard and gummy texture, uncharacteristic darker colour and aftertaste in hybrid meat products (Smarzyński et al., 2019). All of the used additives in meat processing are potential sources of microbiological contamination and the cricket powder is no exception (Vandeweyer et al., 2017). A highly valuable property of chitin and its derivates is the antimicrobial effect which could not be confirmed by our results.

Scholliers et al. (2020) suggested that the gel matrix of the hybrid meat products will be affected due to the content of chitin and the different protein structure of insect flours. The microstructure images of both batters and cooked sausages showed a coalescence of air and fat droplets into larger agglomerates which could be due to their rupture by sharp chitin fragments. This phenomenon could also explain the harder texture of the cooked sausages with the replacement of lean pork meat with cricket powder.

5. Conclusion

The presented results showed that the 5% replacement of lean pork meat with cricket powder affected in the most positive way the cooked sausages. Higher percent replacements led to a darker colour, hard, dry and chewy texture. The addition of cricket powder did not affect water activity and microbiological status, therefore did not compromise the safety of the cooked sausages. Further studies of the water and oil binding capacity of the cricket powder are needed. The stability of emulsions containing cricket powder should be studied for a better understanding of the mechanism of gel formation and overcoming texture flaws.

Conflict of interests

All the authors declare no conflict of interest.

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