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POSSIBILITIES FOR PARTIAL REPLACEMENT OF PORK MEAT IN COOKED SAUSAGES BY MEALWORM FLOUR

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ABSTRACT

Dried and grinded "mealworms" or the larvae of *Tenebrio molitor* in form of flour contain up to two thirds of protein and fat. Therefore, the objective of this study was to investigate the possibility for partial replacement of pork meat by mealworm flour expressed through the changes in color, texture, microbiological status and morphology of cooked sausages. The experimental cooked sausages were prepared by substituting 1.5% (CM1), 2% (CM2) and 3% (CM3) pork meat with mealworm flour. It was found that up to 3% substitution of pork meat with mealworm flour (CM3) decreases the free water in the cooked sausages. The lack of difference in a_W after replacement of pork meat with mealworm flour does not compromise the shelf life and safety of the produced cooked sausages. As the amount of added mealworm flour increases the structural strength, plastic strength and springiness of experimental cooked sausages decreases. The substitution of 1.5% pork meat with mealworm flour (CM1) was the most appropriate for sausage processing without negative color changes. The appropriate pH of mealworm flour, together with the formed stable emulsions and good water binding capacity both before and after cooking, confirmed the potential of suitable meat substitute in meat industry. The microbial status of the experimental cooked sausages (CM1, CM2 and CM3) increased during storage, but still in the regulated limits for cooked meat products.

1.Introduction

In recent years, demand for animal protein has increased due to the exponential growth of the human population and changes in consumption habits brought about by the globalization of the market. These factors led to the development of industrial production systems, resulting in negative environmental effects (FAO, 2013). Many researches have been conducted to explore the feasibility of using non-meat ingredients as proteins of plant origin or milk proteins to promote a healthier meat sausage product, emphasizing the physicochemical properties and sensory characteristics in relation to the addition of new ingredients and substitution of animal fats (Syuhairah *et al.*, 2016).

Insects, as an alternative source of proteins for the food and feed industry, have a number of advantages over raw materials of plant origin (Cruz-López *et al.*, 2022). The consumption of water and energy for the cultivation of insects is minimal. Other positive environmental aspect is the opportunity to feed the insects with organic waste (Vlahova-Vangelova *et al.*, 2022). According to data from the Food and Agriculture Organization, agricultural production annually generates 27% waste (FAO, 2013) worth 750 billion dollars (The Economist, 2014), which is not utilized at the moment. In the light of circular economy development strategy this saved energy and water resources, would be used in the cultivation of cereals (Van Huis *et al.*, 2013). In addition, insects contain high quality protein and essential amino acids and are a good source of fatty acids and minerals (Talens *et al.*, 2022).

Edible insect proteins have the potential to become meat replacers in cooked sausage processing due to their appropriate technological characteristics, such as pH and emulsion capacity (Kim *et al.,* 2016). Even more, the insect flours are rich in microelements and unsaturated fatty acids and can be used as an additional nutritional component with potential health benefits (Van Huis *et al.*, 2013). Due to their rearing some authors suggest they have a higher microbial load and potentially compromise food safety (Vandeweyer *et al.*, 2017).

The term "mealworm" refers to the larvae of *Tenebrio molitor*, Family *Tenebrionidae* (dark beetles). According to EFSA, the larvae of Tenebrio *molitor* larvae are extremely rich in protein, fat and fiber and they can be used raw, dried and ground in the form of flour. Dried yellow mealworms have excellent potential as an alternative to plant sources in feed. Their protein content varies between 41 and 66%, and at the same time is a source of high-quality protein (Turck *et al.,* 2021).

The overall objective of this study was to investigate the possibility for partial replacement of pork meat by 1.5%, 2% and 3% mealworm flour (MF) expressed through the changes in color, texture and microbiological status of in cooked sausages.

2. Materials and methods

2.1. Materials

The sausages were prepared using chilled pork shoulder (pH 6.10) and chilled pork bacon (pH 6.00) purchased from the local market (48 h *post mortem*).

The mealworm flour was obtained from live larvae of *T. Molitor* (70 days hatched), provided by the manufacturer "VI BI EF PRO" LTD (Petrich, Bulgaria). After 48 h fasting, live larvae were conventionally frozen (chilled at -20°C, QUIGG, UFT-Plovdiv, Bulgaria) for 72 h, then blanched in boiling water for 45 s, drained out, dried using conventional drying rack (60°C, 6 h, LUMEL) and finally grounded in a blender. The Proximate composition of mealworm flour is presented in Table 1. Mealworm flour pH was pH - 6.90 and color parameter: L* - 49.78, a* - 5.24 and b* - 8.44.

Table 1. Proximate composition of mealworm flour (*T.Molitor* larvae)

Parameters	
Proteins (%)	62.46±1.32
Fats (%)	14.04±0.67
Ash content (%)	3.00±0.20
Carbohydrates (%)	19.48±0.75
Moisture (%)	1.03±0.06

2.2. Sausages processing

The refrigerated (0-4°C, 48 h post mortem) pork meat was cut on pieces to approximately 50 g, and mixed with nitrite salt, phosphates and ice in cutter machine with a final temperature of batter 12-14 °C (Table 2).

Table 2. Formulations of the cooked sausages

Ingredients, %	**Samples**			
	C	**CM1**	**CM2**	**CM3**
Pork shoulder	60.00	59.25	59.00	58.05
Pork bacon	40.00	39.25	39.00	38.50
Mealworm flour (MF)	0.00	1.50	2.00	3.00
Ice	10.00	10.00	10.00	10.0
Sodium tripolyphosphate	0.20	0.20	0.20	0.20
Nitrite salt (0.55% $NaNO_2$)	2.00	2.00	2.00	2.00

The filling mass (batter) was separated of four equal portions (3 kg each). The experimental sausages were prepared by substituting 1.5% (CM1), 2% (CM2), 3% (CM3) meat with mealworm flour (MF). The filling mass (batter) was filled in gas and moisture impermeable polyamide casings and the sausages (appr. 250 g each) were cooked at 86°C until core temperature of 72°C was reached. After cooking, the sausages were cooled in an ice bath and stored in refrigerator (0-4°C). For the part of analyses a batter was used. The batter measurements were carried out up to 2 h after obtaining.

2.3. Analysis methods

2.3.1. Instrumental color determination

Konica Minolta colorimeter CR-410 (Konica Minolta Holding, Inc., Ewing, New Jersey, USA) was used to evaluate the lightness (L* value), the redness (a* value) and the yellowness (b* value) of the color (Smarzyński *et al.,* 2019).

2.3.2. pH measurement

The pH value of the samples was measured electro-potentiometrically with a portable Meat pH meter HI99163 (Hanna instruments Inc., 270 George Washington Hwy Smithfield) (Pereira *et al.,* 2011).

2.3.3. Free water

The free water of the batters and cooked sausages was determined by drying at 105°C (Vandeweyer *et al.,* 2017).

2.3.4. Free water

Water activity of the cooked sausages was measured using a Novasina AG CH-8853 (Zurich, Switzerland) (Vandeweyer *et al.,* 2017).

2.3.5. Texture profile analysis (TPA)

The texture profile (TPA) was conducted by the method, described by Bourne (2002) with certain modifications (Vassilev *et al.*, 2012). For evaluation of the texture profile the following parameters were measured: Plastic strength - the force of resistance of the body on which it is applied by a sharp tip; Structural strength - the resistance of the body to the deformation force applied by a rounded tip and Springiness - the capacity of the body to recover its initial form after the deformation force is removed. An OB - 05 penetrometer (Labor, Hungary) was used to conduct all the measurements. Before carrying out of the analysis the samples were left for 20 min at room temperature.

2.3.6. Microbiological status

The preparation and decimal dilutions of suspension were done according ISO 6887-2:2017. The microbiological status was presented by the Total viable count (TVC), Coliforms and Yeasts and Molds count (ISO4833-1:2013/ Amd 1:2022; ISO 4833-2:2013/ Amd 1:2022).

2.3.7. Light microscopy

The structure of cooked sausages cuts (2x2x1 cm) was prefixed using 10% formalin solution. A gradually increasing ethanol solutions (from 50% to absolute) were used for dehydration. After bleaching with acetone samples were transferred in xylene for one night and then embedded in paraffin. For the staining of the 5 μm thick slices was used haematoxylin-eosin (Barbut *et al.* 2005). The capturing of the images was done at x100 magnification using a light microscope (Olimpus BX41TF, Japan) equipped with digital camera (Olimpus SC30, Japan).

2.3.8. Data analysis

All results are expressed as mean ± standard error of means (SEM), with $n \geq 5$ for all analyses. The results are processed by methods of variation statistics with various software packages Microsoft Office 365 (SAS Institute Inc, 2018). The comparison in the values of the parameters is done by t-test at Student and ANOVA for all samples from one side and inside in the levels of the factors for statistically significant differences at the level of confidence $\alpha = 0.05$ ($p \leq 0.05$).

3.Results and discussions

3.1. Technological characteristics

The cross-cut surface color of the sausages is an important factor determining positive perception by consumers. One of the main stated disadvantages of plant or insect enriched hybrid meat products is the deterioration of sensory characteristics, for example their color (Talens *et al.,* 2022). The replacement of pork meat with mealworm flour (*T. molitor*) led to a decrease the color lightness (L*) of both batter and cooked sausages. After 3% substitution with mealworm flour (CM3), the decrease was 7% ($p<0.05$) in batters and 8.7% ($p \leq 0.05$) in sausages, respectively (Table 3). Reduce in color lightness was observed in frankfurters made with the addition of mealworm flour (Choi *et al.*, 2017) and sausages with grasshopper flour (Cruz-López *et al.*, 2022). On the one hand, the darker color was expected, since the flour is darker in color. On the other hand, the color change may be due to enzymatic browning activated by heat treatment (Azzollini *et al.*, 2016) or a simple physical phenomenon explained by the decreased free water and increased pH, hence the decreased light scattering of the cross-cut surface (Pereira *et al.*, 2011).

The red color in the experimental cooked sausages increased linearly with percent meat replacement. In the meantime, no significant differences in the color yellowness (b*) was observed between all batter samples. On the 7^{-th} day of storage (0-4°C), the b* value was highest in CM3 (with 3% MF). The addition of mealworms (*T. molitor* larvae) increased the yellowness in frankfurters, too (Choi *et al.*, 2017). Previous studies found that the addition of cricket powder (*Acheta domesticus*) also affect b* values of formulated sausages (Ho *et al.*, 2022). From the point of view of the indicator red component (a*) the use of 1.5% mealworm meal is the most appropriate for the hybrid sausages processing without negative color changes. The data are consistent with the assumption made by Ho *et al.* (2022), namely that higher protein, fat and carbohydrate content and dietary fiber in insect flours influencing color changes.

The replacement of pork meat with mealworm did not affect pH of all examined batters (Table 3). After the applied heat treatment was established a significant increase in pH values in all cooked sausages ($p<0.05$). On the 1^{-st} day of storage (0-4°C) the lowest was pH in the control sausages C, and the highest - in CM3 (with 3% MF). The tendency was maintained on the 7^{-th} day of the experiment. The stabilization of pH in CM1, CM2 and CM3 during storage (0–4 °C) indicates suitable conditions for maintaining the cross-bind protein structure after heat treatment. A shift in pH in acidic reaction would disrupt the stability of the formed emulsion, associated with denaturation and disruption of cross-links in the protein matrix (Kim *et al.*, 2017). The pH can be used as an indicator of the batter stability in the production of sausages. The use of additives with a low pH carries the risk of decrease to the isoelectric point of the meat proteins, lead to low stability of the formed emulsion, poor texture and high cooking losses. Conversely, mealworm flour (*T. molitor)* is a suitable substitute in the production of hybrid meat products, due to its pH (Table 1) which favors the formation of a stable emulsion. Similar results were found by Ho *et al.* (2022) in the production of hybrid meat products with cricket powder (*Acheta domesticus*). The highest free water was found in the control batter C ($p<0.05$). The substitution of pork meat with mealworm flour led a decrease of free water in batter and cooked sausages (CM1, CM2 and CM3). Similar results were reported by Scholliers *et al.* (2020a) after partial replacement of meat by superworm (*Zophobas morio* larvae) in cooked sausages.

The appropriate pH of mealworm flour, together with the formed stable emulsion and good water binding ability both before and after cooking, confirmed the potential of suitable meat substitute in meat industry. Conversely, Wang *et al.* (2019) found a negative influence after partial replacement of meat with *Lentinula edodes* on cooking losses, used an indirect indicator of the emulsion stability.

Water activity (a_W) of all cooked sausages differ in no significant range ($p>0.05$) between 0.931 and 0.940 for CM3 and control, respectively. As well as a_W is considered as crucial indicator for microbial growth (Melgar-Lalanne *et al.*, 2019), the lack of difference after addition of mealworm flours up to 3% does not compromise the shelf life and safety of the hybrid meat sausages.

Table 3. Technological characteristics of batter and cooked sausages during storage (0–4 °C)

	Type sample/ Storage time		L*	a*	b*	pH	Free water (%)
C	Batter	-	66.66 ± 0.34^{d}	13.17 ±0.07^{d}	13.47 ±0.10^{a}	6.41 ±0.02^{a}	21.91 ±0.13^{d}
	Cooked sausages	Day 1	68.14 ±0.05^{d,y}	7.86 ±0.03^{a,x}	9.65 ±0.02^{c,y}	6.21 ±0.03^{a,x}	27.68 ±0.07^{d,x}
		Day 7	66.97 ±0.10^{c,x}	9.82 ±0.04^{b,y}	8.82 ±0.03^{b,x}	6.36 ±0.04^{a,y}	35.04 ±0.06^{c,y}
CM1	Batter	-	64.34 ±0.08^{c}	10.80 ±0.09^{c}	13.37 ±0.12^{a}	6.45 ±0.03^{a}	16.94 ±0.07^{b}
	Cooked sausages	Day 1	63.74 ±0.07^{c,x}	8.91 ±0.05^{b,x}	8.71 ±0.04^{a,x}	6.69 ±0.02^{b,y}	23.82 ±0.09^{c,x}
		Day 7	63.66 ±0.06^{b,x}	9.75 ±0.07^{b,y}	8.63 ±0.07^{a,x}	6.60 ±0.02^{b,x}	32.49 ±0.11^{b,y}
CM2	Batter	-	63.47 ±0.14^{b}	10.07 ±0.05^{b}	13.31 ±0.09^{a}	6.40 ±0.05^{a}	15.11 ±0.10^{a}
	Cooked sausages	Day 1	63.19 ±0.06^{b,y}	9.81 ±0.05^{d,y}	8.88 ±0.06^{a,y}	6.61 ±0.03^{b,x}	20.01 ±0.04^{a,x}
		Day 7	62.47 ±0.09^{a,x}	9.43 ±0.02^{a,x}	8.63 ±0.04^{a,x}	6.60 ±0.03^{b,x}	28.54 ±0.07^{a,y}
CM3	Batter	-	62.30 ±0.13^{a}	9.07 ±0.07^{a}	13.22 ±0.13^{a}	6.41 ±0.02^{a}	19.18 ±0.90^{c}
	Cooked sausages	Day 1	62.65 ±0.08^{a,x}	9.57 ±0.09^{c,x}	9.00 ±0.09^{b,x}	6.60 ±0.02^{b,x}	21.98 ±0.04^{b,x}
		Day 7	62.60 ±0.09^{a,x}	10.23 ±0.06^{c,y}	9.65 ±0.09^{c,y}	6.61 ±0.04^{b,x}	28.47 ±0.06^{a,y}

Note: ^{a,b,c,d} superscripts show significant difference ($p<0.05$) in means by columns (among the samples); ^{x,y} superscripts show significant difference ($p<0.05$) in means during storage.

Our results confirm the conclusion made by Ho *et al.* (2022), that meat replacement with mealworm flour causes minor changes in quality parameters but improves nutritional value and is environmentally friendly. Perhaps the origin of the flour and its technological characteristics such as pH, fat and protein content and solubility are the key to stability of the insect-based hybrid meat products.

3.2. Texture characteristics

The replacement of pork meat with mealworm up to 3% does not change the plastic strength (Table 4) of the batter ($p>0.05$). Obviously, the appropriate pH of the flour, its high protein content and low amount of water are suitable for stabilizing the native structure. However, after heat treatment, differences in the texture of the cooked sausages with pork meat substitution were found. Compared to control C, plastic strength was 3 times lower ($p<0.05$) in CM3 sausages (with 3% mealworm flour) and two times lower ($p<0.05$) in the cooked sausages with 2% mealworm flour (CM2). The 1% substitution of pork meat did not affect significantly ($p>0.05$) the plastic strength in the cooked sausages at the 1^{-st} day of storage (0-4°C). The opposite trend is observed in the structural strength (Table 4). In batter with 3% replaced pork meat (CM3) the structural strength increased twice ($p<0.05$). After 2% addition of *T. Molitor* flour (CM2) structural strength did not differ to control C ($p>0.05$). With an increase of MF, the structural strength of the insect-based hybrid cooked sausages decreases. Compared to the control, in CM3 the structural strength was 60% (Day 1) and 35% (Day 7) lower, respectively.

Table 4. Texture profile of batter and cooked sausages during storage (0–4 °)

	Type sample/ Storage time		Plastic strength (kg/cm²)	Structural strength (kg/cm²)	Springiness (%)
C	Batter	-	0.80±0.19[a]	5.90±0.21[a]	-
	Cooked sausages	Day 1	16.80±0.42[c,x]	232.70±20.50[b,x]	86.0±10.0[b,y]
		Day 7	26.60±0.39[d,y]	314.10±4.50[d,y]	44.0±2.0[b,x]
CM1	Batter	-	1.20±0.19[a]	8.20±0.28[a,b]	-
	Cooked sausages	Day 1	14.70±0.26[c,x]	199.90±30.10[a,b,x]	84.0±10.0[b,x]
		Day 7	19.30±0.30[c,x]	260.10±5.60[c,y]	48.0±2.0[b,y]
CM2	Batter	-	1.50±0.31[a]	7.00±0.24[a,b]	-
	Cooked sausages	Day 1	8.50±0.37[b,x]	158.00±21.40[a,x]	77.0±3.0[a,b,y]
		Day 7	11.90±0.42[b,x]	212.00±8.10[b,y]	38.0±6.0[a,b,x]
CM3	Batter	-	1.80±0.34[a]	10.20±0.16[b]	-
	Cooked sausages	Day 1	5.50±0.27[a,x]	142.80±26.00[a,x]	62.0±11.0[a,y]
		Day 7	8.40±0.25[a,x]	231.50±9.10[b,y]	29.0±7.0[a,x]

Note: [a,b,c,d] superscripts show significant difference ($p<0.05$) in means by columns (among the samples); [x,y] superscripts show significant difference ($p<0.05$) in means during storage.

With the increase of meat replacement with mealworm flour, the structural strength of the cooked sausages decreases. The gelation and emulsification process runs during cooling with formation of hydrogen bonds and improves the textural properties in final product (Scholliers *et al.*, 2020b). As a result, the textural properties are improved. But the mixtures of certain proteins, such as insect proteins, might be unable to aggregate in gel structure and therefore the gel strength decrease. Similar to our results were obtained after 5% meat replacing by superworm (*Zophobas morio* larvae) resulted in a drastic decrease in the textural properties (Scholliers *et al.*, 2020b).

In parallel with the structural strength, the springiness of the cooked sausages also decreases ($p<0.05$), and it was the lowest after meat substitution with 3% mealworm flour (CM3). Lower hardness in hybrid meat products (containing insect flour) were obtained by Choi *et al.*, (2017). The opposite effect was found by Kim *et al.*, (2016) and Kamani *et al.*, (2019). Probably the source of the protein flour - insects, plant proteins, milk proteins is a determinant of the texture of the hybrid product. A similar hypothesis was also expressed by Scholliers *et al.*, (2020b). They also add one more factor - the temperature during the cooking, as with the increase up to 90°C a partial improvement of textural properties in hybrid cooked sausages with *Zophobas morio* larvae was found.

3.3. Microbiological status

The replacement of pork meat with mealworm flour didn't increase the total viable count (TVC) (Table 5, Day 1). TVC in CM2 and CM3 were found lower compared to the control C and CM1 ($p<0.05$). In the same time lowest coliforms' count was found in cooked sausages with 2% MF (CM2) ($p<0.05$) and in CM3 they weren't even detected. At 1% substitution of pork meat with mealworm flour no significant difference as found compared to the control sausages No significant difference was found between the control C and CM1 and CM2 ($p>0.05$) in yeasts and molds growth, and minimal was the value in CM3 ($p<0.05$). On the 7^{-th} day of storage (0-4°C), minimal TVC growth was established in control C and CM1, followed by CM3 and CM2 ($p<0.05$). The lowest were found coliforms in control C ($p<0.05$). In the same time no significant difference between all experimental cooked sausages (CM1, CM2 and CM3) was established.

At the end of the studied period (Day 7, 0+4°C) lowest was growth of yeasts and molds in the control C and CM1.

Table 5. Microbiological status of the cooked sausages during storage (0–4 °C)

	Type sample/ Storage time		TVC (CFU/g)	Coliforms (CFU/g)	Yeasts & Molds (CFU/g)
C	Cooked sausages	Day 1	$5.29\pm0.18^{b,y}$	$5.12\pm0.21^{b,y}$	$4.32\pm0.28^{b,y}$
		Day 7	$3.59\pm0.33^{a,x}$	$2.30\pm0.37^{a,x}$	$2.75\pm0.62^{a,x}$
CM1	Cooked sausages	Day 1	$5.34\pm0.53^{b,y}$	$4.64\pm0.32^{b,x}$	$3.72\pm0.42^{b,y}$
		Day 7	$4.23\pm0.42^{a,b,x}$	$3.45\pm0.46^{b,x}$	$2.60\pm0.43^{a,x}$
CM2	Cooked sausages	Day 1	$4.06\pm0.37^{a,x}$	$3.18\pm0.24^{a,x}$	$3.15\pm0.39^{a,b,x}$
		Day 7	$4.47\pm0.41^{b,x}$	$3.45\pm0.38^{b,x}$	$3.20\pm0.61^{b,x}$
CM3	Cooked sausages	Day 1	$5.04\pm0.64^{a,b,x}$	N.F.	$3.00\pm0.21^{a,x}$
		Day 7	$4.73\pm0.32^{b,x}$	3.27 ± 0.55^{b}	$3.33\pm0.55^{b,x}$

Note: ^{a,b,c,d} superscripts show significant difference ($p<0.05$) in means by columns (among the samples); ^{x,y} superscripts show significant difference ($p<0.05$) in means during storage.

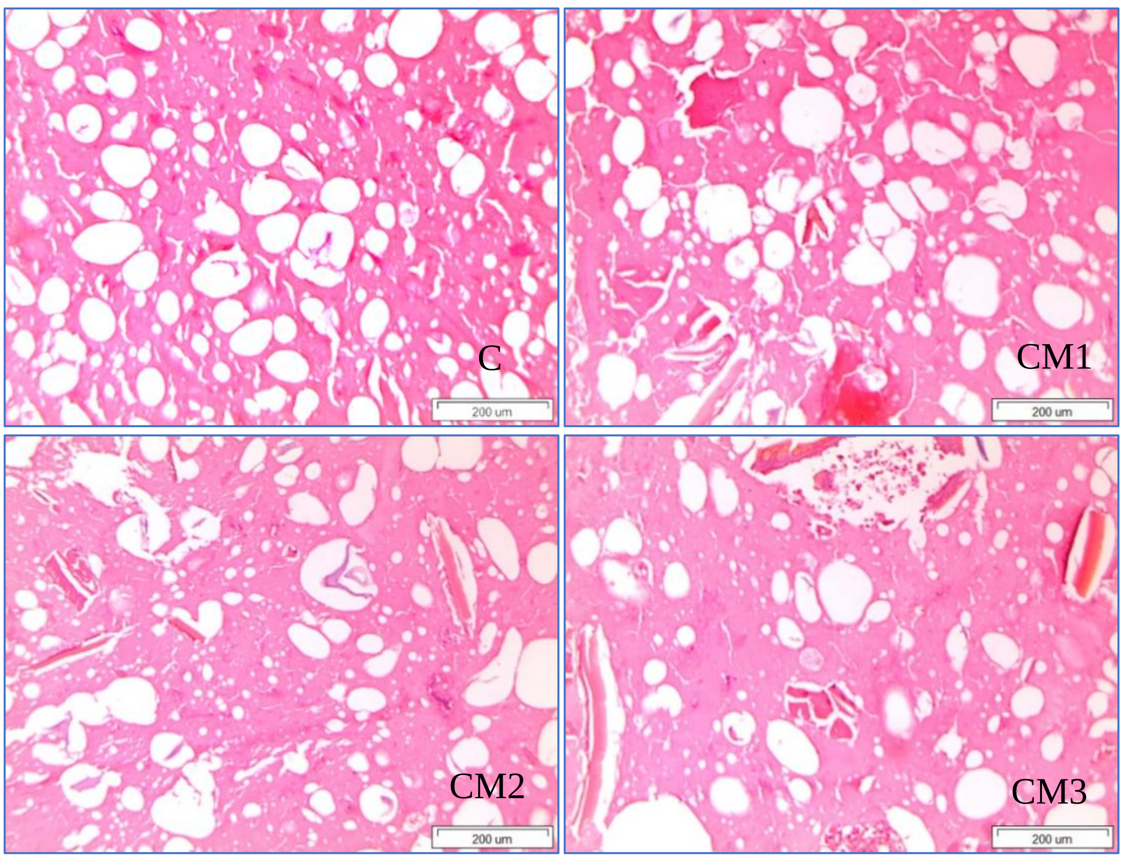

Figure 1. Light microscopy of cooked sausage at x100 time magnification

The obtained results confirm previous researches (Vandeweyer *et al.,* 2017) indicated that meat replacers, spices, salting materials like insect flour are a source of additional microbial contamination. However, the initial rate of microbial contamination was not increased by the meat replacement. The microbial growth during storage was similar in both control C and all experimental cooked sausages. According to the literature the chitin from the exoskeleton of insects exhibits antimicrobial properties (Shin *et al.,* 2019). The results obtained did not show a significant antimicrobial effect after the meat substitution with mealworm flour.

3.4. Light microscopy

At Figure 1 are presented the microstructural images of the four investigated cooked sausages. Their matrix was made up of fat droplets wrapped in protein film, the water droplets are dispersed throughout the myofibrillar and connective tissue fragments. Control C had a characteristic uniform gel matrix. On the other hand, in all samples with MF the gel matrix was disturbed and there were clearly observable solid particles. A lager air bubbles and fat droplets were observed due to coalescence. Similar dose depended enlargement of the air bubbles due to the addition of insect flours was reported by Vlahova-Vangelova et al. (2022).

4. Conclusions

Overall color changes in the cooked sausages with 1.5% substitution of pork meat was minimal. Reduce in color lightness (L*) was observed by the darker flour color and due to enzymatic browning activated by heat treatment. The red component (a*) of the color increased after meat replacement with mealworm flour. The appropriate pH of mealworm flour (*T. molitor* larvae), together with the formed stable emulsions and good water binding ability both before and after cooking, confirmed the potential of suitable meat substitute in meat industry.

Meat replacement up to 3% mealworm flour decreases the free water in the experimental cooked sausages. The lack of difference in water activity after substitution of pork meat with mealworm flour up to 3% does not compromise the shelf life and safety of the produced meat products. The percent of meat replacement with mealworm flour in the cooked sausages affect their texture profile summarized by the decrease in structural and plastic strength and springiness of the experimental cooked sausages.

The expected microbial load of the mealworm flour affects TVC, coliforms count and yeasts & molds count in some sense established in the cooked sausages with 2 and 3% meat replacement. Yet the set limits for cooked meat products were not surpassed and their quality and safety were no compromised.

5.References

Azzollini, D., Derossi, A., Severini, C. (2016): Understanding the drying kinetic and hygroscopic behaviour of larvae of yellow mealworm (*Tenebrio molitor*) and the effects on their quality. *Journal of Insects as Food and Feed*, *2*(4), 233-243. http://doi.org/10.3920/jiff2016.0001

Barbut, S., Zhang, L., Marcone, M. (2005). Effects of pale, normal, and dark chicken breast meat on microstructure, extractable proteins, and cooking of marinated fillets. *Poultry science*, 84(5), 797-802. http://doi.org/10.1093/ps/84.5.797

Choi, Y.S., Kim, T.K., Choi, H.D., Park, J.D., Sung, J.M., Jeon, K.H., Paik, H. D., Kim, Y.B. (2017). Optimization of replacing pork meat with yellow worm (*Tenebrio molitor* L.) for frankfurters. *Korean Journal of Food Science and Animal. Resources,* 37(5), 617. http://doi.org/10.5851/kosfa.2017.37.5.617

Cruz-López, S.O.; Álvarez-Cisneros, Y.M.; Domínguez-Soberanes, J.; Escalona-Buendía, H.B.; Sánchez, C.N. (2022). Physicochemical and Sensory Characteristics of Sausages Made with Grasshopper (*Sphenarium Purpurascens*) Flour. *Foods,* 11(5), 704. http://doi.org/10.3390/foods11050704

Economist (2014). Food loss and its intersection with food security. Global food security index 2014 Special report of the intelligence unit of The Economist

FAO (2013). Food wastage footprint: impact on natural resources. Summary report. Food and Agriculture Organization of the United Nation, Rome.

Ho, I., Peterson, A., Madden, J., Huang, E., Amin, S., Lammert, A. (2022). Will It Cricket? Product Development and Evaluation of Cricket (*Acheta domesticus*) Powder Replacement in Sausage, Pasta, and Brownies. *Foods*, 11(19), 3128. http://doi.org/10.3390/foods11193128

ISO 4833-1:2013/Amd 1:2022 Microbiology of the food chain - Horizontal method for the enumeration of microorganisms - Part 1: Colony count at 30 °C by the pour plate technique - Amendment 1: Clarification of scope.

ISO 4833-2:2013/Amd 1:2022 Microbiology of the food chain — Horizontal method for the enumeration of microorganisms — Part 2: Colony count at 30 °C by the surface plating technique — Amendment 1: Clarification of scope.

ISO 6887-2:2017 Microbiology of the food chain — Preparation of test samples, initial suspension and decimal dilutions for microbiological examination — Part 2: Specific rules for the preparation of meat and meat products.

Kamani, M.H., Meera, M.S., Bhaskar, N., Modi, V.K. (2019). Partial and total replacement of meat by plant-based proteins in chicken sausage: Evaluation of mechanical, physico-chemical and sensory characteristics. *Journal of Food Science and Technology*, 56(5), 2660-2669. http://doi.org/10.1007/s13197-019-03754-1

Kim, H.W., Setyabrata, D., Lee, Y.J., Jones, O.G., Kim, Y.H.B. (2016). Pre-treated mealworm larvae and silkworm pupae as a novel protein ingredient in emulsion sausages. Innovative *Food Science & Emerging Technologies,* 38, 116-123. https://doi.org/10.1016/j.ifset.2016.09.023

Kim, H.W., Setyabrata, D., Lee, Y., Jones, O.G., Kim, Y.H.B. (2017). Effect of house cricket (*Acheta domesticus*) flour addition on physicochemical and textural properties of meat emulsion under various formulations. *Journal of Food Science,* 82(12), 2787-2793. https://doi.org/10.1111/1750-3841.13960

Melgar-Lalanne, G., Hernández-Álvarez, A., Salinas-Castro, A. (2019): Edible insects processing: Traditional and innovative technologies. *Comprehensive Reviews in Food Science and Food Safety,* 18(4), 1166-1191. https://doi.org/10.1111/1541-4337.12463

Pereira, A.G.T., Ramos, E.M., Teixeira, J.T. Cardoso, G.P. Ramos, A.D.L.S. & Fontes, P.R. (2011). Effects of the addition of mechanically deboned poultry meat and collagen fibers on quality characteristics of frankfurter-type sausages. *Meat Science,* 89(4), 519-525. https://doi.org/10.1016/j.meatsci.2011.05.022

SAS Institute Inc. (2018). SAS/STAT® 15.1User's GuideThe GAMPL Procedure.

Scholliers, J., Steen, L., Fraeye, I. (2020a). Partial replacement of meat by superworm (*Zophobas morio* larvae) in cooked sausages: Effect of heating temperature and insect: Meat ratio on structure and physical stability. *Innovative Food Science & Emerging Technologies,* 66, 102535. https://doi.org/10.1016/j.ifset.2020.102535

Scholliers, J. Steen, L., Fraeye, I. (2020b). Structure and physical stability of hybrid model systems containing pork meat and superworm (*Zophobas morio* larvae): The influence of heating regime and insect: Meat ratio. *Innovative Food Science & Emerging Technologies*, 65, 102452. https://doi.org/10.1016/j.ifset.2020.102452

Shin, C.S., Kim, D.Y. Shin, W.S. (2019). Characterization of chitosan extracted from Mealworm Beetle (*Tenebrio molitor, Zophobas morio*) and Rhinoceros Beetle (*Allomyrina dichotoma*) and their antibacterial activities. *International journal of biological macromolecules*, 125, 72-77. https://doi.org/10.1016/j.ifset.2020.102452

Smarzyński, K., Sarbak, P., Musiał, S., Jeżowski, P., Piątek, M., Kowalczewski, P. Ł. (2019). Nutritional analysis and evaluation of the consumer acceptance of pork pâté enriched with cricket powder-preliminary study. *Open Agriculture, 4*(1), 159-163. https://doi.org/10.1515/opag-2019-0015

Syuhairah, A., Huda, N., Syahariza, Z.A., Fazilah, A. (2016). Effects of vegetable incorporation on physical and sensory characteristics of sausages. *Asian Journal of Poultry Science,* 10(3), 117-125. https://doi.org/10.3923/ajpsaj.2016.117.125

Talens, C., Llorente, R., Simó-Boyle, L., Odriozola-Serrano, I., Tueros, I., Ibargüen, M. (2022). Hybrid Sausages: Modelling the

Effect of Partial Meat Replacement with Broccoli, Upcycled Brewer's Spent Grain and Insect Flours. *Foods*, 11(21), 3396. https://doi.org/10.3390/foods11213396

Turck, D., Castenmiller, J., De Henauw, S., Hirsch-Ernst, K.I., Kearney, J., Maciuk, A., Knutsen, H.K. (2021). Safety of dried yellow mealworm (*Tenebrio molitor* larva) as a novel food pursuant to Regulation (EU) 2015/2283. *EFSA Journal*, 19(1), 6343. https://doi.org/10.2903/j.efsa.2021.6343

Van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., Vantomme, P. (2013). Edible insects: future prospects for food and feed security (No. 171). Food and agriculture organization of the United Nations.

Vandeweyer, D., Lenaerts, S., Callens, A. Van Campenhout, L. (2017). Effect of blanching followed by refrigerated storage or industrial microwave drying on the microbial load of yellow mealworm larvae (*Tenebrio molitor*). *Food Control*, 71, 311-314. https://doi.org/10.1016/j.foodcont.2016.07.011

Vassilev, K., Balev, D., Ivanov, G., Yancova, Y., Iliev, G. (2012). Effect of superchilling treatment and storage conditions on the technological properties of chicken breast meat. *Scientific works of University of Food Technologies*, *59*(1), 464-468. ISSN (CD): 1314-7102 Online ISSN: 2535-1311 Proceedings of the 59rd Scientific Conference with International Participation 'Food Science, Engineering and Technology – 2012', October 19 – 20, 2012, UFT, Plovdiv, Bulgaria [in Bulgarian]

Vlahova-Vangelova, D.B., Balev, D.K., Dinkova, R.H., Kolev, N.D. & Stankov, S.S. (2022). Technological and sensory properties of sponge cakes containing cricket flour (acheta domesticus). *Carpathian Journal of Food Science and Technology*, 14(1), 89-97. https://doi.org/10.34302/crpjfst/2022.14.1.7

Wang, L.Y., Guo, H.Y., Liu, XJ., Jiang, G.C., Li, C., Li, X.Y. Li, Y. (2019). Roles of *Lentinula edodes* as the pork lean meat replacer in production of the sausage. *Meat Science*, 156, 44-51. https://doi.org/10.1016/j.meatsci.2019.05.016