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ARTICLE

Optimization of Replacing Pork Meat with Yellow Worm (*Tenebrio molitor* L.) for Frankfurters

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Abstract

The effects of replacing pork meat with yellow mealworms on the physicochemical properties and sensory characteristics of frankfurters were investigated in this study. The control (50% pork ham), T1 (45% pork ham + 5% yellow mealworm), T2 (40% pork ham + 10% yellow mealworm), T3 (35% pork ham + 15% yellow mealworm), T4 (30% pork ham + 20% yellow mealworm), T5 (25% pork ham + 25% yellow mealworm), and T6 (20% pork ham + 30% yellow mealworm) were prepared, replacing lean pork meat with yellow mealworm. The moisture content, lightness, sarcoplasmic protein solubility, hardness, gumminess, chewiness, and apparent viscosity of frankfurters with yellow mealworm were lower than those of the control ($p<0.05$), whereas the content of protein and ash, pH, and yellowness of frankfurters with yellow mealworm were higher than those of the control ($p<0.05$). The fat content of frankfurters in T1 ($p<0.05$) was the highest, and the fat content of treatments decreased with increasing yellow mealworm concentrations ($p<0.05$). Frankfurters with increasing yellow mealworm concentrations had lower color, flavor, off-flavor, and juiciness scores. The overall acceptability was not significantly different in the control, T1, and T2 ($p>0.05$). Thus, the results of this study showed that replacing lean pork meat with up to 10% yellow mealworm successfully maintained the quality of frankfurters at a level similar to that of the regular control frankfurters.

Keywords pork meat, yellow mealworm, novel protein, frankfurter, sensory characteristics

Introduction

Food security is one of the most serious challenges associated with the rapid global population growth. In 2050, the production of animal proteins are estimated to reach 200 million tons per year, assuming that the world population increases by 65% (Kim *et al*., 2016). Proteins from livestock foods constitute the main protein supplements (Tan *et al*., 2015). However, livestock increases the greenhouse effect because of the emission of carbon dioxide (CO_2) and methane gases. Moreover, available lands could be insufficient to not only accommodate human residential areas but also breed livestock animals (Ahn *et al*., 2015). Thus, the substitution of conventional livestock with edible insects as a novel food protein source is necessary. Edible insects can be a valid alternative because of their environmental and nutritional advantages (Van Huis, 2013). Verkerk *et al*. (2007) reported that insect proteins are important novel protein sources, in the next decades, and approximately 40% of traditional meat product consumption will be replaced by novel protein sources.

Edible insects are undeniably rich sources of proteins and other nutrients (Kim *et al*., 2016; Rumpold and Schuter, 2013); however, there are few challenges and gaps in scientific knowledge regarding this topic. Edible insects include Lepidoptera, Coleoptera, Orthoptera, Isoptera, and Hymenoptera (Hwang *et al*., 2015), and silkworm, grasshopper and silk worm pupae are typically used as a food source in Korea (Hwang and Choi, 2015). One of the problems related to edible insect consumption as a human food is unfavorable consumer perception (Tan *et al*., 2015). This problem may be solved by processing edible insects in a less recognizable form and incorporating them in food products (Verkerk *et al*., 2007). Several studies showed that the edible insect protein had emulsion capacity and gel-forming ability to be used as functional food ingredients (Osasona and Olaofe, 2010; Yi *et al*., 2013). Thus, insect proteins as a novel protein source can be used to partially replace meat in processed meat products (So, 2016).

Yellow mealworm (*Tenebrio molitor* L.) in its larval and pupal stages is abundant in protein, and it has the advantage of easy breeding (Ghaly and Alkoaik, 2009; Hwang and Choi, 2015; Li *et al*., 2013). The yellow mealworm has been commercially farmed for human consumption in the world (Chen *et al*., 2009). Yellow mealworms are a readily available source of proteins, lipids, carbohydrates, vitamins, and minerals (Li *et al*., 2013), and a good source of essential amino acids and polyunsaturated fatty acids (Zielińska *et al*., 2015). However, there is a lack of studies explaining the effect of replacing pork meat with yellow mealworm in frankfurters.

Therefore, the objective of this study was to investigate the effects of substituting pork meat with yellow mealworm, on the proximate composition, pH, cooking loss, emulsion stability, protein solubility, texture profile, sensory properties, and apparent viscosity of frankfurters.

Materials and Methods

Yellow mealworm preparation

Yellow mealworms (*Tenebrio molitor* L.) larvae were purchased from Edible Inc. (Korea). Yellow mealworms larvae were washed three times with five volumes of water, and the residue was vacuum dried (60°C) for 12 h and then cooled. The sample was ground in a blender (ABBL-3347; Altenbach, Germany) for 2 min to particle size < 0.5 mm. Dried yellow mealworms larvae (moisture content: 4.15±0.06%, protein content: 49.57±0.45%, fat content: 21.83±1.40%, ash content: 4.22±0.20%, lightness: 25.20±1.10, redness: 25.20±1.10, and yellowness: 25.20±1.10) were vacuum packaged (FJ-500XL; Fujee Tech, Korea) and stored at -4°C until use for frankfurter manufacture.

Frankfurter preparation and processing

Fresh pork ham (*musculus biceps femoris*, *semitendinosus*, and *semimembranosus*) and pork back fat (moisture: 12.61%, fat: 85.64%) were purchased from a local processor 48 h postmortem. Pork ham and pork fat were ground using a meat grinder (PM-70, Mainca, Spain) through an 8-mm plate. Seven different treatments of frankfurters were produced, and the experimental design and compositions of frankfurters are shown in Table 1. The first frankfurters served as the control and were prepared with 50% pork ham, 25% back fat and 25% ice. The remaining six types were prepared as follows: T1, 45% pork ham + 5% yellow mealworm powder; T2, 40% pork ham + 10% yellow mealworm powder; T3, 35% pork ham + 15% yellow mealworm powder; T4, 30% pork ham + 20% yellow mealworm powder; T5, 25% pork ham + 25% yellow mealworm powder; and T6, 20% pork ham + 30% yellow mealworm powder and the composition back fat and ice of each treatment was not different with control.

Table 1. Frankfurter formulations for replacing pork meat with yellow mealworm (units: g/100 g)

Ingredients	Treatments						
	Control	T1	T2	T3	T4	T5	T6
Pork ham	50	45	40	35	30	25	20
Yellow mealworm powder	0	5	10	15	20	25	30
Back fat	25	25	25	25	25	25	25
Ice	25	25	25	25	25	25	25
Total	100	100	100	100	100	100	100
NaCl	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Sodium phosphate	0.15	0.15	0.15	0.15	0.15	0.15	0.15

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Pork ham and yellow mealworm powder were homogenized and ground for 2 min in a silent cutter (Nr-963009; Hermann Scharfen GmbH & Co., Germany). Ice water (2 C), sodium chloride (1.5%), and sodium tripolyphosphate (0.15%) were added to the meat and mixed for 90 s. The pork fat was added after 3 min, and the meat batters were homogenized for 3 min at a temperature below 10°C throughout the batter preparation. Each meat batter was prepared and tested three times in the same producing. After emulsion batter preparation, the emulsion batter was stuffed into 25-mm diameter casings (#240; NIPPI Inc., Japan) using a stuffer (IS-8; Sirman, Italy). The meat batters were heated at 75°C for 30 min in a chamber (MAXi 3501; Kerres, Germany) and then cooled to 21°C. This procedure was performed in triplicate for each frankfurter (Choi *et al*., 2014).

Proximate composition

Compositional properties of frankfurters were analyzed using the Association of Official Agricultural Chemists (AOAC) guidelines (2000). Moisture content (950.46B), fat content (960.69), protein content (981.10), and ash content (920.153) were determined according to AOAC methods.

pH

The pH values of frankfurters were measured in a homogenate (Ultra-Turrax T25, Janke & Kunkel IKA-Labortechnik, Germany) prepared with 5 g of sample and 20 mL distilled water using an electronic pH meter (Model 340, Mettler-Toledo GmbH, Switzerland).

Cooking loss

Cooking loss of frankfurters was calculated as a percentage of the weight differences between raw and cooked frankfurters.

Color

The color of each frankfurter was determined using a Minolta chromameter (CR-410; Minolta Ltd., Japan; illuminate C, calibrated with a white plate, CIE L^*=+97.83, CIE a^*=-0.43, CIE b^*=+1.98) with an 8-mm diameter measuring area and a 50-mm diameter illumination area. Lightness (CIE L^*- value), redness (CIE a^*- value), and yellowness (CIE b^*- value) values were recorded.

Emulsion stability

The frankfurter batters were analyzed for total expressible fluid separation and fat separation using the method of Bloukas and Honikel (1992) with the following modifications. The total expressible fluid and fat separated in the bottom of each graduated glass tube were measured and calculated (Choi *et al*., 2007). The pre-weighed graduated glass tubes were filled with batter and heated for 30 min in a boiling water bath (75°C).

Total expressible fluid separation (mL/g) = [(the water layer (mL) + the fat layer (mL)) / weight of raw meat batter (g)] × 100

Fat separation (mL/g) = [the fat layer (mL) / weight of raw meat batter (g)] × 100

Protein solubility

The frankfurter batters were analyzed for protein solubility using the method of Joo *et al*. (1992). Sarcoplasmic protein and total protein were extracted by phosphate buffer (25 mM potassium phosphate buffer and 1.1 M potassium iodide in 0.1 M potassium phosphate buffer) and centrifuged at 6,000×g for 10 min after overnight. After filtered by Whatman No.1, Sarcoplasmic protein solubility and total protein solubility were determined using the biuret method (Gornall *et al*., 1949). Myofibrillar protein solubility was obtained by determining the difference between the total and sarcoplasmic protein solubilities.

Texture profile analysis

Texture profile analysis (TPA) was conducted at room temperature with a TA.XT*plus* Texture Analyzer (TA.XT 2*i*; Stable Micro Systems Ltd., UK). Prior to analysis, samples were allowed to equilibrate at room temperature. Frankfurters samples were taken from the central portion of each sample (size: 2.5×2.5×2.5 cm) with 10 replicates. The conditions of texture analysis were as follows: pre-test speed 2.0 mm/s, post-test speed 5.0 mm/s, maximum load 2 kg, head speed 2.0 mm/s, distance 8.0 mm, and force 5 g. Values for hardness (N), springiness, cohesiveness, gumminess (N), and chewiness (N) were determined as described by Bourne (1978).

Sensory evaluation

A total of 12 trained-panelists consisting of researchers of the Food Processing Research Center at Korea Food Research Institute (KFRI) in Republic of Korea was used to evaluate the frankfurters. Each frankfurter was evaluated in terms of color, flavor, off-flavor, tenderness, juiciness, and overall acceptability. Frankfurters were cut into quarters (size: 2.5×2.5×2.5 cm) and served to the panelists randomly. Sensory evaluations were conducted under white fluorescent lighting. Panelists were instructed to cleanse their palates between samples using water. The color (1 = extremely undesirable, 10 = extremely desirable), flavor (1 = extremely undesirable, 10 = extremely desirable), off-flavor (1 = extremely undesirable, 10 = extremely desirable), tenderness (1 = extremely tough, 10 = extremely tender), juiciness (1 = extremely dry, 10 = extremely juicy), and overall acceptability (1 = extremely undesirable, 10 = extremely desirable) of the frankfurter samples were evaluated using a 10-point descriptive scale. This analysis was conducted using the hedonic test described by Choi *et al*. (2008).

Apparent viscosity

Meat emulsion batter viscosity was measured with a rotational viscometer (Thermo Haake Visco Tester® 550; Thermo Electron Corporation, Germany) set at 10 rpm. The standard cylinder sensor (SV-2) was placed in a 25-mL metal cup filled with meat emulsion batter at 18°C and allowed to rotate under a constant share rate (s^{-1}) for 30 s before each reading was taken (Shand, 2000).

Statistical analysis

All data were subjected to the analysis of variance (ANOVA) using general linear model (GLM) procedure of SPSS 18.0 software (SPSS Inc., USA) in triplicate to ensure a random effect (blocking factor). When significant ($p<0.05$) treatment effects were shown, Duncan's multiple range tests was used to compare the mean values. Mean values and standard deviation of the means were reported.

Results and Discussion

Proximate composition

The proximate compositions of frankfurters formulated by replacing pork meat with yellow mealworm are given in Table 2. The moisture content of frankfurters with yellow mealworm was lower than that of the control ($p<0.05$) and decreased with increasing yellow mealworm concentrations. The protein content and ash content of frankfurters with yellow mealworm were higher than those of the control ($p<0.05$) and increased with increasing yellow mealworm concentrations. The fat content of frankfurters was the highest in T1 ($p<0.05$) and decreased with increasing yellow mealworm concentrations ($p<0.05$). Although the fat content of meal worm was higher than that of pork meat, the fat content was higher in the control than in the other, which seems to be due to the relative difference in moisture and protein composition. Kim *et al*. (2016) reported that emulsion sausages formulated with insects (mealworm larvae and silkworm pupae) had lower moisture content and higher protein content compared to regular control emulsion sausages. This result could be related with the fact that the insect powder contained higher protein contents compared to lean pork meat at an equal level of formula in the emulsion sausage. Kim *et al*. (2008) indicated that the replacement of 10% lean pork meat with insect (mealworm larvae and silkworm pupae) flour led to increases in solid components, because the insect flour had a dry matter content of 93-95%. Thus, proximate composition depended on the amount of yellow mealworm.

pH, cooking loss, and color

The pH of frankfurters formulated with different combinations of pork ham and yellow mealworm is shown in Table 3. The pH of frankfurters with yellow mealworm was higher than that of the control ($p<0.05$) and increased with increasing yellow mealworm concentrations. These results were in agreement with those of Kim *et al*. (2016), who reported that mealworm larvae and silkworm pupae flours slightly increased the pH of emulsion sausages. They reported that the addition of insect flour directly aff-

Table 2. Proximate composition of frankfurters formulated for replacing pork meat with yellow mealworm

Parameters	Control[1)]	T1	T2	T3	T4	T5	T6
Moisture content (%)	59.76±0.85^{A}	55.38±0.17^{B}	52.81±1.14^{C}	52.27±1.14^{C}	52.17±1.66^{C}	50.98±1.05^{C}	47.54±0.63^{D}
Protein content (%)	10.03±0.80^{F}	13.89±0.64^{E}	14.33±0.66^{DE}	15.64±0.52^{D}	17.48±0.69^{C}	21.10±0.22^{B}	24.00±0.11^{A}
Fat content (%)	20.71±0.27^{C}	26.90±0.57^{A}	24.92±0.28^{B}	20.34±0.67^{C}	18.91±0.95^{D}	16.00±0.16^{E}	14.61±0.38^{F}
Ash content (%)	2.14±0.04^{D}	2.30±0.08^{C}	2.31±0.04^{C}	2.31±0.17^{C}	2.63±0.14^{B}	2.86±0.04^{A}	2.94±0.06^{A}

All values are mean ± standard deviation of three replicates (n=9).

$^{A\text{-}F}$Means within a row with different letters are significantly different ($p<0.05$).

[1)]Control, frankfurters with 50% pork meat + 0% yellow worm; T1, frankfurters with 45% pork meat + 5% yellow worm; T2, frankfurters with 40% pork meat + 10% yellow worm; T3, frankfurters with 35% pork meat + 15% yellow worm; T4, frankfurters with 30% pork meat + 20% yellow worm; T5, frankfurters with 35% pork meat + 25% yellow worm; T6, frankfurters with 30% pork meat + 20% yellow worm.

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Table 3. pH, cooking loss and color of frankfurters formulated for replacing pork meat with yellow mealworm

Parameters		Control[1)]	T1	T2	T3	T4	T5	T6
pH		5.98±0.02^{G}	6.18±0.01^{F}	6.22±0.01^{E}	6.25±0.02^{D}	6.28±0.01^{C}	6.31±0.02^{B}	6.39±0.01^{A}
Cooking loss (%)		6.02±1.09^{D}	5.30±0.20^{D}	5.61±0.12^{D}	12.02±1.35^{C}	12.80±1.73^{C}	14.39±1.39^{B}	17.57±0.64^{A}
Color	L*-value	81.17±0.48^{A}	75.72±0.62^{B}	70.35±0.43^{C}	67.15±0.38^{D}	59.58±0.71^{E}	56.75±0.93^{F}	55.05±0.51^{F}
	a*-value	2.65±0.10^{D}	1.90±0.13^{F}	2.38±0.17^{E}	2.78±0.16^{D}	3.71±0.11^{C}	4.11±0.26^{B}	4.37±0.20^{A}
	b*-value	9.75±0.21^{F}	13.02±0.48^{E}	14.25±0.38^{D}	15.71±0.46^{C}	17.14±0.59^{B}	17.81±0.53^{AB}	18.34±0.77^{A}

All values are mean ± standard deviation of three replicates (n=9).

$^{A-G}$Means within a row with different letters are significantly different (p<0.05).

[1)]Control, frankfurters with 50% pork meat + 0% yellow worm; T1, frankfurters with 45% pork meat + 5% yellow worm; T2, frankfurters with 40% pork meat + 10% yellow worm; T3, frankfurters with 35% pork meat + 15% yellow worm; T4, frankfurters with 30% pork meat + 20% yellow worm; T5, frankfurters with 35% pork meat + 25% yellow worm; T6, frankfurters with 30% pork meat + 20% yellow worm.

ected the pH of emulsion sausages because of higher pH of insect flours compared to lean meat. Hwang and Choi (2015) reported that the pH of foods added with yellow mealworm was affected by the addition of the mealworm powder.

The cooking losses of frankfurters formulated with different yellow mealworm concentrations are shown in Table 3. The cooking loss was the lowest in the control, T1, and T2 frankfurters (p<0.05), and the cooking loss of frankfurters with yellow mealworm increased with increasing yellow mealworm concentrations. Although high pH of yellow mealworm could have positive effect on cooking loss of meat batter (Hwang and Choi, 2015; Kim *et al*., 2016), it makes the meat batter deteriorate in formulation when the lean pork meat is replaced with lots of amount of yellow mealworm powder because the content of myofibrillar protein in the yellow mealworm which can increase in binding capacity of the meat products was denatured through drying process.

In terms of the color values of frankfurters, the lightness of frankfurters with yellow mealworm decreased with increasing concentrations of yellow mealworm, while the yellowness of frankfurters with yellow mealworm increased with increasing yellow mealworm concentrations. These results implied that the addition of yellow mealworm resulted in darker and yellower color of frankfurters. The redness of frankfurters with yellow mealworm increased with increasing yellow mealworm concentrations, while redness of treatments with 15% yellow mealworm (T3) was similar to that of the control. Similar results in color values have been reported by Kim *et al*. (2016) when mealworm larvae and silkworm pupae flours were added to the emulsion sausages. Hwang and Choi (2015) reported that lightness and yellowness of Muffins decreased with increasing mealworm powder concentrations, while redness increased. Therefore, these effects could be due to the color values of the yellow mealworm, as it is a dark and yellow-colored mealworm.

Emulsion stability and protein solubility

Table 4 shows the emulsion stability of frankfurters formulated with lean pork meat replaced by yellow mealworm. The total expressible fluid separation was the highest in T5 and T6 frankfurters (p<0.05), and there was no significant difference among the control, T1, T2, and T3 (p>0.05). The fat separation was the highest in T5 and T6 (p<0.05), and the fat separation showed a tendency similar to that of the total expressible fluid separation. The emul-

Table 4. Emulsion stability and protein solubility of frankfurters formulated for replacing pork meat with yellow mealworm

Parameters		Control[1)]	T1	T2	T3	T4	T5	T6
Emulsion stability (%)	Total expressible fluid separation	7.93±1.35^{C}	6.71±0.41^{C}	6.01±1.35^{C}	6.25±1.78^{C}	18.92±3.58^{B}	21.33±2.46^{A}	20.27±1.81^{A}
	Fat separation	1.05±0.03^{C}	1.24±0.34^{C}	1.32±0.02^{C}	1.25±0.36^{C}	14.43±0.85^{B}	17.70±0.80^{A}	18.26±1.79^{A}
Protein solubility (mg/g)	Sarcoplasmic protein	38.75±0.44^{A}	36.25±1.08^{B}	34.10±0.88^{C}	33.45±0.55^{C}	30.95±0.46^{D}	30.07±0.47^{D}	26.85±0.46^{E}
	Myofibrillar protein	111.65±11.33^{A}	109.05±14.35^{A}	81.30±2.03^{B}	80.85±3.71^{B}	58.75±1.66^{C}	55.35±1.22^{D}	55.34±1.19^{D}
	Total protein	150.40±10.93^{A}	145.30±14.21^{A}	115.40±1.70^{B}	114.30±3.24^{B}	89.70±1.91^{C}	85.42±1.66^{D}	82.20±1.43^{D}

All values are mean ± standard deviation of three replicates (n=9).

$^{A-E}$Means within a row with different letters are significantly different (p<0.05).

[1)]Treatments: Control, frankfurters with 50% pork meat + 0% yellow worm; T1, frankfurters with 45% pork meat + 5% yellow worm; T2, frankfurters with 40% pork meat + 10% yellow worm; T3, frankfurters with 35% pork meat + 15% yellow worm; T4, frankfurters with 30% pork meat + 20% yellow worm; T5, frankfurters with 35% pork meat + 25% yellow worm; T6, frankfurters with 30% pork meat + 20% yellow worm.

sion stability was not affected by replacing lean pork meat with up to 15% yellow mealworm. However, when the replacement was greater than 15%, the emulsion stability tended to be lower because of the increased fat separation. For these reasons, yellow mealworm protein has less emulsifying capacity than muscle protein (Kim *et al*., 2016).

Protein solubility of meat emulsions during the manufacturing process is affected by pH, protein concentration, additives, ionic strength, and thermal conditions (Choi *et al*., 2014; Kim *et al*., 2016). Protein solubility of muscle proteins is an important indicator associated with water holding capacity, emulsion stability, and gel matrix formation, and it considerably affects cooking loss and textural properties of meat emulsion products (Choi *et al*., 2010; Choi *et al*., 2013). The protein solubilities of the meat batters formulated with different combinations of pork ham and yellow mealworm are shown in Table 4. Kim *et al*. (2016) reported that all emulsions showed similar solubility of total, myofibrillar, and sarcoplasmic proteins when 10% lean pork meat was replaced with insect flour. This result was due to the reduction of muscle protein in the initial formulation replacing lean pork meat with yellow mealworm. Although the protein content of yellow mealworm was higher than that of lean pork meat in this study, protein solubility decreased due to characteristics of materials (protein of yellow meal worm was denatured during heat drying process (p<0.05). Myofibrillar protein and sarcoplasmic protein solubility was the highest in the control (p<0.05), whereas Myofibrillar protein and sarcoplasmic protein solubility of the meat batters with yellow mealworm decreased with increasing yellow mealworm concentrations (p<0.05).

Texture profile analysis

Texture profile analysis of frankfurters formulated by replacing lean pork meat with yellow mealworm is shown in Table 5. The control had the highest hardness, gumminess, and chewiness (p<0.05). The hardness, gumminess, and chewiness of frankfurters with yellow mealworm decreased with increasing up to 20% yellow mealworm concentrations. However, the hardness, gumminess, and chewiness of frankfurters with yellow mealworm increased when the yellow mealworm content exceeded 25%, because dehydration of frankfurters during cooking increased. There was no difference in the springiness and cohesiveness between the control and treatments with yellow mealworm, except T6. Kim *et al*. (2016) reported that all emulsion sausages containing insect flours had a higher hardness than that of the control sausage. They reported that the increased hardness of insect treatments was an inescapable result due to the decreased moisture content and increased solid compounds. Hwang and Choi (2015) reported that no significant difference in hardness was found in formulations with increasing mealworm powder concentrations. Similar results have been reported by So (2016) when mealworm larvae flour was added to meat products. The previous study reported that hardness, gumminess, and chewiness decreased as mealworm powder was increasingly added, while springiness and cohesiveness showed no significant differences in the control and treatments with mealworm powder. Thus, frankfurter preparation may use replacing pork meat with up to 15% yellow mealworm to achieve a texture similar to that of the regular frankfurter.

Apparent viscosity

The replacement of pork meat with yellow mealworm significantly affected the apparent viscosity of frankfurter meat batters (Fig. 1). In the control and all treatments with yellow mealworm, meat batter samples exhibited thixotropic behavior, with apparent viscosity values that decreased with increasing rotation time. The apparent viscosity

Table 5. Textural attributes of frankfurters formulated for replacing pork meat with yellow mealworm

Parameters	Control[1)]	T1	T2	T3	T4	T5	T6
Hardness (N)	3.93±0.41^{A}	2.81±0.24^{B}	2.51±0.33^{BC}	2.42±0.17^{BC}	2.28±0.27^{C}	2.80±0.63^{B}	2.82±0.44^{B}
Springiness	0.98±0.01^{A}	0.98±0.08^{A}	0.98±0.02^{A}	0.98±0.06^{A}	0.98±0.01^{A}	0.97±0.02^{A}	0.92±0.04^{B}
Cohesiveness	0.38±0.02^{A}	0.38±0.03^{A}	0.37±0.02^{A}	0.40±0.04^{A}	0.37±0.07^{A}	0.35±0.05^{A}	0.29±0.03^{B}
Gumminess (N)	1.51±0.20^{A}	1.06±0.09^{B}	0.94±0.15^{BC}	0.98±0.38^{BC}	0.86±0.16^{BC}	0.94±0.13^{BC}	0.79±0.11^{C}
Chewiness (N)	1.47±0.21^{A}	1.04±0.09^{B}	0.92±0.15^{BC}	0.97±0.38^{BC}	0.84±0.17^{CD}	0.93±0.15^{BCD}	0.72±0.08^{D}

All values are mean ± standard deviation of three replicates (n=9).

$^{A-D}$Means within a row with different letters are significantly different (p<0.05).

[1)]Control, frankfurters with 50% pork meat + 0% yellow worm; T1, frankfurters with 45% pork meat + 5% yellow worm; T2, frankfurters with 40% pork meat + 10% yellow worm; T3, frankfurters with 35% pork meat + 15% yellow worm; T4, frankfurters with 30% pork meat + 20% yellow worm; T5, frankfurters with 35% pork meat + 25% yellow worm; T6, frankfurters with 30% pork meat + 20% yellow worm.

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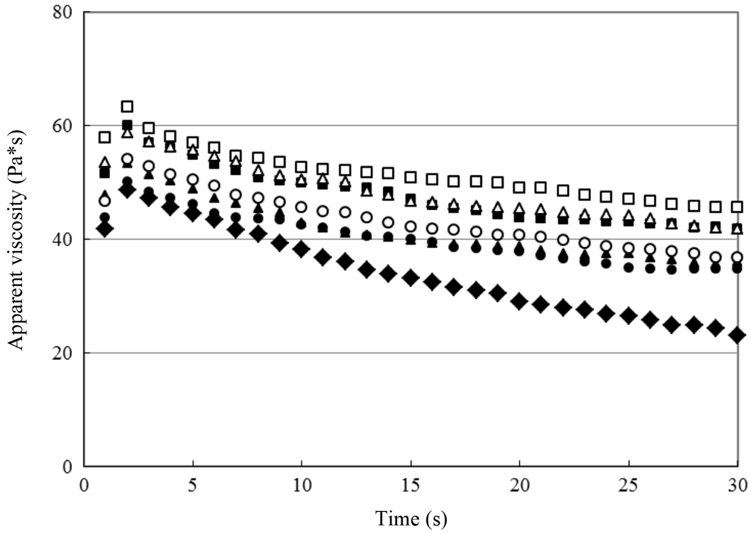

Fig. 1. Apparent viscosity of frankfurters formulated for rep- lacing pork meat with yellow mealworm. Control(□), frankfurters with 50% pork meat + 0% yellow worm; T1(■), frankfurters with 45% pork meat + 5% yellow worm; T2(△), frankfurters with 40% pork meat + 10% yellow worm; T3(▲), frankfurters with 35% pork meat + 15% yellow worm; T4(○), frankfurters with 30% pork meat + 20% yellow worm; T5(●), frankfurters with 35% pork meat + 25% yellow worm; T6(◆), frankfurters with 30% pork meat + 20% yellow worm.

of the control was higher than that of all treatments with yellow mealworm ($p<0.05$). This effect could be due to the fact that yellow mealworm may reduce water binding capacity and fat binding capacity (Kim *et al*., 2016). According to Choi *et al*. (2012), the emulsion viscosity was intimately related with emulsion stability in emulsion meat product. This effect was attributed to high-viscosity emulsions that are not easily broken. Thus, several studies have suggested that higher apparent viscosity may help to improve the quality on cooking loss, emulsion stability and water holding capacity of emulsified meat products (Choi *et al*., 2014; Lee *et al*., 2008; Yapar *et al*., 2006).

Sensory characteristics

The sensory characteristics of frankfurters formulated by replacing lean pork meat with yellow mealworm are shown in Table 6. The control samples had the highest color, flavor, off-flavor, and juiciness scores ($p<0.05$), whereas frankfurters with increasing yellow mealworm concentrations had lower color, flavor, off-flavor, and juiciness scores. The tenderness scores were the highest in the control and T1 ($p<0.05$). The overall acceptability was the highest in the control ($p<0.05$); however, the overall acceptability was not significantly different among the control, T1, and T2 ($p>0.05$). So (2016) reported that the color, taste, and overall acceptability of foods had the

Table 6. Sensory characteristics of frankfurters formulated for replacing pork meat with yellow mealworm

Parameters	Control[1)]	T1	T2	T3	T4	T5	T6
Color	7.82 ± 0.87^{A}	6.91 ± 0.94^{AB}	6.09 ± 0.70^{BC}	5.45 ± 1.21^{CD}	4.82 ± 1.17^{DE}	4.55 ± 1.29^{DE}	4.18 ± 1.54^{E}
Flavor	7.09 ± 0.83^{A}	6.73 ± 0.65^{AB}	6.45 ± 1.21^{AB}	6.00 ± 1.61^{BC}	5.18 ± 0.75^{CD}	4.64 ± 1.43^{DE}	4.09 ± 1.38^{E}
Off-flavor	7.27 ± 1.19^{A}	6.55 ± 1.13^{AB}	6.27 ± 1.35^{AB}	5.82 ± 1.33^{BC}	4.91 ± 1.30^{CD}	4.64 ± 1.36^{CD}	4.18 ± 1.72^{D}
Tenderness	7.18 ± 0.98^{A}	7.00 ± 0.89^{A}	6.36 ± 1.43^{AB}	5.82 ± 1.33^{BC}	4.82 ± 1.08^{CD}	4.36 ± 1.50^{D}	3.73 ± 1.62^{D}
Juiciness	7.36 ± 0.67^{A}	6.73 ± 0.79^{AB}	6.55 ± 0.93^{AB}	6.27 ± 0.90^{AB}	6.18 ± 1.72^{AB}	5.73 ± 2.10^{B}	5.36 ± 2.25^{B}
Overall acceptability	7.27 ± 0.90^{A}	6.73 ± 0.79^{AB}	6.45 ± 1.63^{AB}	5.55 ± 1.37^{BC}	4.91 ± 1.04^{CD}	4.27 ± 1.42^{D}	3.82 ± 1.78^{D}

All values are mean ± standard deviation of three replicates (n=9).

$^{A\text{-}E}$Means within a row with different letters are significantly different ($p<0.05$).

Color, flavor, off-flavor, tenderness, juiciness, and overall acceptability of the samples were evaluated using a 10-point descriptive scale (1 = extremely undesirable, 10 = extremely desirable).

[1)]Control, frankfurters with 50% pork meat + 0% yellow worm; T1, frankfurters with 45% pork meat + 5% yellow worm; T2, frankfurters with 40% pork meat + 10% yellow worm; T3, frankfurters with 35% pork meat + 15% yellow worm; T4, frankfurters with 30% pork meat + 20% yellow worm; T5, frankfurters with 35% pork meat + 25% yellow worm; T6, frankfurters with 30% pork meat + 20% yellow worm.

highest scores in meat products with 50% mealworm powder. Hwang and Choi (2015) reported that the flavor, taste, and overall acceptability of foods had the highest scores when approximately 1-8% mealworm powder was added. Thus, frankfurters produced by replacing lean pork meat with up to 10% yellow mealworm had the highest overall acceptability, which was similar to that of the regular control frankfurters.

Conclusion

The replacement of lean pork meat with yellow mealworm had important effects on the quality characteristics of frankfurters. Replacing lean pork meat with yellow mealworm in frankfurters would be beneficial for the substitution of animal proteins with novel protein sources. Frankfurters formulated with a combination of 40% pork meat and 10% yellow mealworm were similar on cooking loss, emulsion stability, protein solubility, and overall acceptability to regular control frankfurters. Therefore, the combination of pork meat and yellow mealworm in the formulation successfully replaced partially lean pork meat with yellow mealworm, maintaining the quality of frankfurters.

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