Korean Journal for Food Science of Animal Resources

pISSN 1225-8563
eISSN 2234-246X

Korean J. Food Sci. An. 37(3): 351~359 (2017)
DOI https://doi.org/10.5851/kosfa.2017.37.3.351

ARTICLE

Physicochemical Properties of Meat Batter Added with Edible Silkworm Pupae (*Bombyx mori*) and Transglutaminase

Yoo-Sun Park, Yun-Sang Choi[1], Ko-Eun Hwang, Tae-Kyung Kim, Cheol-Won Lee, Dong-Min Shin, and Sung Gu Han*

Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 05029, Korea
[1]Food Processing Research Center, Korean Food Research Institute, Seongnam 13539, Korea

Abstract

This study was conducted to investigate the physicochemical properties of meat batters prepared with fresh pork meat, back fat, water, and salt and formulated with three different amounts (5%, 10%, and 15%) of silkworm pupae (*Bombyx mori*) powder and transglutaminase (TG). Meat batters formulated with silkworm pupae powder showed significantly higher contents of protein and ash than control batter. Addition of silkworm pupae to batter also showed significantly lower cooking loss than the control. Moreover, meat batter containing 15% silkworm pupae showed no significant difference in redness value compared to the control. In addition, pH, viscosity, hardness, gumminess, and chewiness were improved after the addition of silkworm pupae. Furthermore, meat batter formulated with TG and silkworm pupae showed improved hardness, gumminess, chewiness and viscosity compared to control batter. Addition of 1% TG with 15% silkworm pupae to meat batter resulted in significantly higher pH, textures, and viscosity. Our data suggest that both silkworm pupae and TG can be added to meat batter to improve its physicochemical properties. Therefore, combination of silkworm pupae and TG could be a new nutritional and functional source for meat products.

Keywords edible insects, silkworm pupae, *Bombyx mori*, transglutaminase, meat batter

Introduction

Edible insects have been consumed in more than 110 countries over the world (Rumpold and Schlüter, 2013). Mealworm (*T. molitor*), cricket (*Acheta domesticus*), and silkworm (*Lepidotera*) account for a high proportion of edible insects (Nowak *et al*., 2016). Studies about edible insects as conventional sources of nutrition have been increased gradually (Tan *et al.*, 2016). Sah and Jung (2012) have reported that compositions of edible insects include about 45-55% protein and 40-57% fat on dry matter basis. In addition, insects have higher environmental efficiency compared to livestock. The landscape used to rear insect and greenhouse gases emission from insect rearing are less than those for rearing livestock. Therefore, it has been suggested that using insects is an effective way to fulfill future nutrient requirement (Rumpold and Schlüter, 2013). Edible insects as additives to various foods have been conducted in previous studies. For example, pasta added with mealworm powder (5-20%) has shown increased sensory preference (Kim *et*

Received May 16, 2017
Revised May 27, 2017
Accepted May 28, 2017

*Corresponding author
Sung Gu Han
Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 05029, Korea
Tel: +82-2-450-0526
Fax: +82-2-455-1044
E-mail: hansg@konkuk.ac.kr

al., 2014). In addition, pork patty added with 20% of mealworm powder has improved flavor and protein content (Kim *et al.*, 2015). Kim *et al.* (2008) have reported that mealworm powder can improve the binding properties of pork patties. Nevertheless, meat products added with silkworm pupae powder have been insufficiently examined.

Silkworm pupae is one of major edible insects consumed in Asia such as Vietnam, Indonesia, China, and Korea (Baker *et al*., 2016). Silkworm pupae can be obtained as a by-product from sericulture business. These by-products of sericulture business are ordinarily consumed as a street food. However, most silkworm pupae are wasted. Utilization of silkworm pupae in commercial products could result in added value. Park and Park (1986) have suggested that defatted silkworm pupa is a good protein source when it is added to emulsified food. Jeon and Park (1992) have reported that enzymatically hydrolyzed silkworm pupae can enhance the retention capacity of water and oil compared to non-treated silkworm pupae. However, consumers have raised concerns about chemically treated foods. Thus, it is necessary to use a binder for silkworm pupae to improve their functional ability without chemical treatment. To improve the binding properties of processed meat, several binders such as carrageenan, isolated soy protein, and transglutaminase have been typically used in the production of meat products (Choi *et al.*, 2015).

Transglutaminase (TG) is an enzyme isolated from microorganism. It can conduct cross-linkage with glutamine and lysine from protein molecule. Meat products added with TG have shown improved texture and cooking yield (Choi *et al.*, 2015; Lee and Chin, 2009). Furthermore, a combination of non-meat ingredient and TG has increased the hardness and reduced the cooking loss of frankfurter (Choi *et al.*, 2016). However, the effect of TG in combination with edible insect proteins on physicochemical properties of meat products has not been reported yet.

Therefore, the aim of this study was to evaluate the effect of a combination silkworm pupae and TG on physicochemical properties of meat batter to provide basic data for industrialization of silkworm pupae in meat processing. Proximate analysis was performed in the current study. In addition, pH, color, apparent viscosity, cooking loss, and texture profile analysis of meat batters were determined in this study.

Materials and Methods

Preparation of silkworm pupae powder

Silkworm pupae were purchased from a local market and then dried in vacuum dryer (DRV622DA, Toyo Seisakusho Kaisha Ltd., Japan) at 40°C. Dried silkworm pupae (L*, 49.94±0.24; a*, 7.96±0.27; b*, 33.63±0.30; pH, 6.39±0.01; Moisture, 5.50±0.17%; Protein, 54.28±1.71%; Fat, 25.69±1.99%; Ash, 4.10±0.07%) were grinded into powder, passed through a 25 mesh sieve (Chung Gye Sang Gong Sa, Korea), and stored in polyethylene bags using a vacuum packing system (FJ-500XL, Fujee Tech, Korea). Sealed powder samples were preserved at -20°C until use.

Preparation and processing of meat batter system

The method of making meat batter with TG (BISION, Korea) and silkworm pupae powder was followed the method used by Herrero *et al*. (2008). Main ingredients, pork lean meat, and back fat were purchased from a local market. All visible connective tissue and evident fat were eliminated from lean pork meat. Chilled meat was ground into 4 mm in diameter using a meat grinder (PM-70, Manica, Spain). Eight different meat batters were produced. The experimental design and formulations are shown in Table 1. The first meat batter served as control was prepared without adding silkworm pupae or TG. The follow-

Table 1. Formulations of meat batter samples added with silkworm pupae and TG

Ingredients (units: %)	Treatments[1)]							
	Control		T1		T2		T3	
	TG non added	TG added	TG non added	TG added	TG non added	TG added	TG non added	TG added
Pork meat	85	85	85	85	85	85	85	85
Water	15	15	15	15	15	15	15	15
Total	100	100	100	100	100	100	100	100
Sodium chloride (NaCl)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Silkworm pupae powder	0	0	5	5	10	10	15	15
Transglutaminase (TG)	0	1	0	1	0	1	0	1

ing combinations of silkworm pupae were used; T1: 5% silkworm pupae; T2: 10% silkworm pupae; T3: 15% silkworm pupae. For TG added treatments, it has been reported that 1% TG addition has the most effect in improving the texture, gel strength, and cooking yield of meat products (Tseng *et al.*, 2000). Therefore, 1% TG was added to meat batter in this study. Meat batter was processed using a silent cutter (Nr-963009, Scharfen, Germany). Completed batter models were vacuum packed (FJ-500XL, Fujee Tech, Korea) and stored at 4°C 12 h before reacting with TG (Min and Green, 2008). After storage, meat batter was stuffed into collagen casing using a stuffer (Stuffer IS-8, Sirman, Italy) and heated at 75°C in a water-bath (Model 10-101, Dae Han Co., Korea) for 30 min.

Proximate analysis

Proximate composition of meat batter was analyzed using AOAC (1995) method. Moisture content was measured based on weight loss after drying in a drying oven (SW-90D, Sang Woo Scienctific Co., Korea) 24 h at 105°C in order to get rid of all moisture. Protein content of respectively cooked samples was determined using Kjeldahl method with an automatic Kjeldahl Nitrogen Analyzer (Kjeltec auto sampler system 1035 analyzer, Foss Tecator AB, Sweden). Fat content was determined using Soxhlet method with a soxhlet solvent extraction system (Büchi Extraction System B-816 ECE, Büchi AG, Switzerland). Ash content was determined following AOAC method 923.03.

pH

To determine pH values, 5 g of meat batter sample was blended with 20 mL of distilled water for 1 min using a homogenizer (Ultra-Turrax T25, Janke and Kunkel, Germany). The pH was then measured with a pH meter (Navi F-51, HORIBA, Japan). Before measuring pH, the detector was calibrated with pH 4 and pH 7 buffer. All treatments were performed in quadruples.

Color measurement

Batter sample was placed in a petri dish to record color values using a calibrated colorimeter (Minolta Chroma meter CR-210, Minolta Co., Japan; illuminate C, calibrated with a white plate, CIE L*=+97.83, CIE a*=-0.43, CIE b* =+1.98). Cross section samples of cooked meat batters were measured. The following criteria were used: CIE L* (+ lightness, - darkness), CIE a* (+ redness, - greenness), and CIE b* (+ yellowness, - blueness).

Apparent viscosity

Meat batter sample was filled into a 25 mL metal cup and fixed under standard cylinder sensor (SV-2). Viscosity was measured using a rotational viscometer (HAKKE Viscotester® 500, Thermo Electron Corporation, Germany) under constant shear at s^{-1} for 30 s before each reading was taken.

Cooking loss

Stuffed meat batters were weighed before heated at 75°C in a water-bath (Model 10-101, Dae Han Co., Korea) for 30 min. Before measuring cook loss, cooked samples were cooled at room temperature for 30 min. Cooking loss was estimated using the following formulation:

Cooking loss (%) = [(the weight of raw sample (g) - the weight of cooked sample (g) / weight of raw sample (g)] × 100

Texture profile analysis (TPA)

Cooked batter was cut into samples with height of 2.5 cm. TPA of unified sample was then measured with a texture analyzer (TA-XT2i, Stable Micro Systems Ltd., Surrey, England). The following conditions were used for texture analysis: pre-test speed, 2.0 mm/s; post-test speed, 5.0 mm/s; head speed, 2.0 mm/s; and distance, 4.0 mm. The analysis was performed at room temperature and repeated 6 times for each sample. The average and standard deviation were then calculated from the six measurements.

Statistical analysis

For all data analyses, SPSS 20 (SPSS Inc., USA) was used. Analysis of variance (ANOVA) was used to determine the significance of main effect. Duncan's multiple range test was used to determine differences between means. Student's *t*-test was used to determine significant difference between TG non-added and TG added treatments. Statistical significance was considered at $p<0.05$.

Results and Discussion

Proximate composition

Results of proximate compositions of meat batters added with different levels of silkworm pupae powder in the presence or absence of TG are shown in Table 2. Moisture contents of meat batters were significantly decreased with increasing levels of silkworm pupae powder, in agreement with results of Hwang and Choi (2015) showing that moi-

Table 2. Approximate analysis of meat batters formulated with silkworm pupae at various levels with or without TG

[1)] Treatments	Moisture (%)		Protein (%)		Fat (%)		Ash (%)	
	TG non added	TG added	TG non added	TG added	TG non added	TG added	TG non added	TG added
Control	72.96±0.08^{a}	72.40±0.07^{a}	18.25±1.69^{b}	19.93±0.58^{c}	5.61±0.35^{b}	5.22±0.27	2.44±0.05^{c}	2.52±0.03^{b}
T1	69.38±0.24^{b}	67.97±0.17^{b}	19.34±0.20^{bB}	22.43±0.22^{bcA}	6.20±0.38^{ab}	6.51±1.05	2.49±0.01^{bc}	2.53±0.03^{b}
T2	66.19±0.33^{c}	64.41±0.01^{c}	19.91±1.08^{bB}	23.74±1.70^{bA}	7.07±0.57^{a}	7.43±1.07	2.56±0.04^{ab}	2.68±0.05^{b}
T3	63.11±0.35^{d}	62.10±0.10^{d}	26.58±1.53^{aB}	29.89±2.10^{aA}	7.09±0.53^{a}	7.73±1.57	2.63±0.04^{a}	3.08±0.22^{a}

All values are mean±SD of three replicates.

[1)]Treatments: Control, meat batter formulated without silkworm pupae powder and TG; T1, meat batter formulated with 5% silkworm pupae powder; T2, meat batter formulated with 10% silkworm pupae powder; T3, meat batter formulated with 15% silkworm pupae powder.

[a-d]Means with different superscripts within a same column differ significantly (p<0.05).

[A,B]Indicate significant differences in average scores among groups compared (p<0.05).

sture content was decreased in food treated with mealworm powder. However, addition of TG had no significant effect on moisture content of meat batter. Many researchers have reported that TG has no effect on moisture content of meat products (Lee and Chin, 2009; Pietrasik *et al.*, 2007). Protein content of meat batter was increased with increasing levels of silkworm pupae. Protein content of silkworm pupae powder was 54.28%. This might have resulted in the increase of protein content in meat batters added with silkworm pupae. Treatments with TG added resulted in significant increase in protein contents than treatments without any addition of TG. However, control samples without any addition of silkworm pupae showed no significant difference in protein content between TG added and non-added treatments. It has been reported that proteins cross-linked by TG have higher molecular weight than those not treated by TG. Such cross-linking reactions might have resulted in more compact protein molecules (Gujeral and Rosell, 2004). Therefore, the increase in protein content after treatment with TG might be due to higher amount of linkage between TG and free amino groups of silkworm pupae. Fat contents of meat batters added with silkworm pupae powder (6.20% to 7.09%) were higher than those (5.61%) of the control. However, fat contents were not significantly different among TG treatments. Choi *et al*. (2016) have reported that the incorporation of sea mustard and TG does not change fat contents of frankfurters. Ash content in silkworm pupae was 4.10%. Ash content in meat batter was gradually and significantly increased with increasing level of silkworm pupae addition. These results were in agreement with results of Min *et al*. (2016) showing that protein, fat, and ash contents in foods added with mealworm powder were higher than those in control foods. Silkworm pupae contain minerals and amino acids, including essential amino acids and sulphur-containing amino acids (Zhou and Han, 2006) that could increase ash content of products.

pH and color evaluation

Results of pH, L* values (lightness), a* values (redness), and b* values (yellowness) of meat batters are summarized in Table 3. The pH value of meat batter containing silkworm pupae was higher than that of the control. This might be to the fact that the pH of silkworm pupae was 6.39. It has been reported that silkworm pupae and mealworm can increase the pH of meat batter, suggesting that addition of insect can directly influence the pH of meat emulsion (Kim *et al*., 2016). The pH of meat batter treated with TG was higher than that of meat batter without TG treatment. This might be due to the fact that TG has a wide range of pH (from 6.5 to 7.0) (Meiying *et al.*, 2002).

Regarding color evaluation of meat batters, L* value was decreased whereas b* value was increased with the addition of silkworm pupae powder. Similar trends in L* value and b* value have been reported in a study of Hwang and Choi (2015) showing that addition of different levels of mealworm into foods has reduced L* value but increased b* value. Min *et al.* (2016) have also reported that the addition of mealworm powder to foods can reduce the L* value. It has been shown that increased concentration of termite can darken the color of food due to maillard reaction occurring among amino acids, peptides, and proteins which causes browning (Kinyuru *et al.*, 2009). The a* value of meat batter and cooked meat is important. It represents the appearance of meat product which determines consumer preference (Steenkamp and van Trijp, 1996). Control and 15% silkworm pupae added samples (T3) after cooking had higher a* values than other treatments without any addition of TG. Silkworm is one of those insects that produce melanin in nature (Sug-

Table 3. Results of pH and color measurement of meat batters formulated with various levels of silkworm pupae with or without TG

[1] Treatments		pH		L*		a*		b*	
		TG non added	TG added	TG non added	TG added	TG non added	TG added	TG non added	TG added
Uncooked	Control	5.69±0.01^{dB}	5.80±0.01^{dA}	61.55±1.40^{aA}	58.84±0.73^{bB}	9.37±0.44^{aB}	13.31±0.87^{aA}	11.18±0.92^{d}	12.38±0.34^{d}
	T1	5.82±0.01^{cB}	5.91±0.02^{cA}	54.77±0.67^{cB}	62.31±0.71^{aA}	7.36±0.33^{cB}	8.35±0.24^{bA}	18.52±0.42^{c}	18.68±0.34^{c}
	T2	5.94±0.01^{bB}	5.97±0.01^{bA}	57.08±1.50^{b}	55.80±0.78^{c}	8.43±0.52^{bA}	7.12±0.30^{cB}	20.72±0.83^{b}	20.95±0.62^{b}
	T3	6.01±0.03^{aB}	6.08±0.01^{aA}	55.67±0.38^{c}	55.57±0.74^{c}	7.48±0.34^{cA}	6.69±0.20^{cB}	22.28±0.79^{a}	22.45±0.24^{a}
Cooked	Control	5.89±0.07^{dB}	6.04±0.02^{dA}	72.12±0.63^{aA}	69.92±0.44^{cB}	5.12±0.41^{a}	5.33±0.26^{a}	10.87±0.45^{d}	10.67±0.22^{d}
	T1	6.05±0.01^{cB}	6.13±0.01^{cA}	62.98±1.39^{bB}	66.28±0.46^{dA}	4.53±0.21^{b}	4.52±0.12^{b}	15.75±0.70^{c}	16.24±0.42^{c}
	T2	6.13±0.01^{bB}	6.17±0.01^{bA}	63.69±0.52^{bA}	62.43±0.98^{bB}	4.46±0.08^{b}	4.56±0.14^{b}	18.78±0.36^{b}	18.82±0.38^{b}
	T3	6.18±0.01^{a}	6.20±0.03^{a}	59.40±0.30^{cA}	58.39±0.61^{aB}	4.97±0.37^{a}	5.31±0.24^{a}	21.07±0.46^{a}	21.21±0.69^{a}

All values are mean±SD of three replicates.
[1]Treatments: Control, meat batter formulated without silkworm pupae powder and TG; T1, meat batter formulated with 5% silkworm pupae powder; T2, meat batter formulated with 10% silkworm pupae powder; T3, meat batter formulated with 15% silkworm pupae powder.
[a-d]Means with different superscripts within a same column differ significantly (p<0.05).
[A,B]Indicate significant differences in average scores among groups compared (p<0.05).

umaran, 2002). Its yellow to reddish brown pheomelanin might have increased a* and b* values of treatments. Results of color evaluation for meat batters with or without TG treatment showed no significant difference. However, meat batter added with TG showed reduced L* value except T1. Similar results have been reported by Lee and Chin (2009) showing that pork sausage added with TG has decreased L* value due to formulation of additives and TG.

Apparent viscosity

Resutls of apparent viscosities of meat batters added with various concentrations of silkworm pupae with or without TG are shown in Fig. 1. Viscosity was increased by the addition of silkworm pupae powder and TG. T3 treatment showed the highest viscosity among different meat batters without TG. Various edible insects have functional properties such as water and oil absorption capacity and emulsifying and foaming ability that could improve viscosity (Assielou *et al.*, 2015; Park and Park, 1986). Higher pH than isoelectric point could improve binding characteristics of meat emulsions because myosin and actomyosin gel strengths are increased with higher pH (optimum 5.5-6.0) (Zorba *et al.*, 2005). The pH value of meat batter added with silkworm pupae was increased from

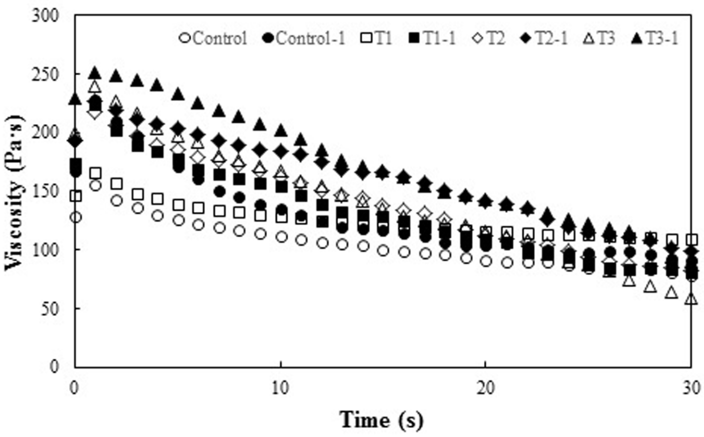

Fig. 1. Changes in apparent viscosity of meat batters formulated with various levels of silkworm pupae with or without TG.
[1]Treatments: Control(○): meat batter without silkworm pupae powder without TG, Control-1(●): meat batter without silkworm pupae powder with TG, T1(□): meat batter with 5% silkworm pupae powder without TG, T1-1(■): meat batter with 5% silkworm pupae powder with TG, T2(◇): meat batter with 10% silkworm pupae powder without TG, T2-1(◆): meat batter with 10% silkworm pupae powder with TG, T3(△): meat batter with 15% silkworm pupae powder without TG, T3-1(▲): meat batter with 15% silkworm pupae powder with TG.

5.82 to 6.01. Observed results with control batters having the lowest viscosity whereas treatments samples added with silkworm pupae and TG having higher viscosity values might be due to cross-link between TG and silkworm pupae protein. The viscosity of the meat batter added with TG in T3 was higher than that of any other treatments with TG. Hong *et al.* (2012) have observed that viscosity of pork myofibrillar protein is increased by the addition of TG, consistent with our results. Ionescu *et al.* (2008) have shown that the increase in viscosity of myofibrillar protein from beef with TG treatment is due to catalyzed TG with protein chains. The cross-linkage between TG and protein can affect the viscosity of food, making it stiffer and more rigid than the control, thus improving the viscosity (Gujral and Rosell, 2004). This finding signifies that silkworm pupae can improve the viscosity of meat batter while the addition of TG also enhances the rheological property of meat batter.

Cooking loss

Results of cooking loss of meat batters containing different amounts of silkworm pupae with TG treatment are shown in Fig. 2. Cooking loss of meat batter was the highest in the control. It was decreased after silkworm pupae powder was added. Kim *et al.* (2016) have suggested that silkworm pupae and mealworm can reduce the cooking loss of emulsion sausage due to reduced moisture content. Similar result of reduced cooking loss with increasing edible insect level has been reported by Kim *et al.* (2008) for pork patties added with silkworm powder. The significant decrease of cooking loss for meat batter added with silkworm powder might be due to pH and viscosity. High pH can affect the degree of net electrostatic repulsion between myofilaments that regulate water to locate in meat matrix, thus resulting in reduced cooking loss (Kim *et al.*, 2010). In general, cooking loss is associated with viscosity, an indicator of binding ability of meat batter. Choe *et al.* (2013) have reported that viscosity of meat batter is increased when cooking loss is decreased. However, TG addition had no significant effect on cooking loss of meat batter, similar to results of Stevenson *et al*. (2013) on chicken protein gels and those of Dimitrakopoulou *et al.* (2005) on pork. These results are also in agreement with those of Chin *et al.* (2009) showing that there is no significant difference in cooking loss of protein gel after it is treated with a combination of TG and konjac powder. This result was probably due to increased salt content by adding silkworm pupae (salinity, 1.8%). High salt concentration can affect water-entrapment in protein matrix structure, thus decreasing cooking loss (Chin *et al*., 2009).

Texture profile analysis (TPA)

Results of texture profile analysis for meat batters formulated with silkworm pupae powder and TG are summarized in Table 4. Generally, texture in food makes a significant contribution to its overall quality (Bourne, 2002). Hardness, gumminess, and chewiness of meat batters were increased when silkworm pupae level was increased. Gumminess and chewiness showed the same trend as hardness. In fact, there are hardness-related test based on the definition of gumminess and chewiness (Lin *et al*., 2000). Similar results have been obtained by Min *et al.* (2016) showing that increasing mealworm level has significantly increased the hardness of foods. It has been reported that

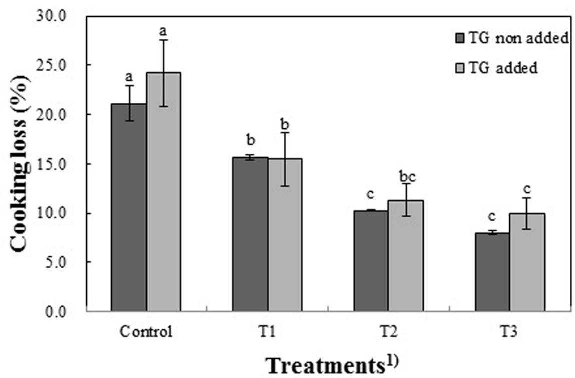

Fig. 2. Cooking loss of meat batters formulated with various levels of silkworm pupae with or without TG. [1)]Treatments: Control, meat batter formulated without silkworm pupae powder and TG; T1, meat batter formulated with 5% silkworm pupae powder; T2, meat batter formulated with 10% silkworm pupae powder; T3, meat batter formulated with 15% silkworm pupae powder. The vertical bars show the standard deviation. [a-c] Means in treatments with different letters are significantly different (p<0.05).

Table 4. Texture profile analysis (TPA) of meat batters formulated with various levels of silkworm pupae with or without TG

[1)]Treatments	Hardness (kg)		Cohesiveness		Springiness		Gumminess		Chewiness	
	TG non added	TG added	TG non added	TG added	TG non added	TG added	TG non added	TG added	TG non added	TG added
Control	0.25 ± 0.03^{dB}	0.48 ± 0.03^{cA}	0.47 ± 0.02^{B}	0.50 ± 0.03^{A}	0.81 ± 0.06	0.81 ± 0.04^{b}	0.12 ± 0.01^{dB}	0.24 ± 0.02^{cA}	0.09 ± 0.01^{dB}	0.20 ± 0.02^{cA}
T1	0.45 ± 0.02^{cB}	0.73 ± 0.04^{bA}	0.47 ± 0.02^{B}	0.52 ± 0.02^{A}	0.83 ± 0.04	0.82 ± 0.05^{b}	0.21 ± 0.01^{cB}	0.38 ± 0.02^{bA}	0.18 ± 0.02^{cB}	0.31 ± 0.03^{bA}
T2	0.70 ± 0.02^{bB}	0.85 ± 0.03^{aA}	0.48 ± 0.02	0.50 ± 0.01	0.83 ± 0.05	0.84 ± 0.03^{ab}	0.34 ± 0.02^{bB}	0.42 ± 0.02^{aA}	0.28 ± 0.03^{bB}	0.35 ± 0.02^{aA}
T3	0.77 ± 0.03^{aB}	0.86 ± 0.04^{aA}	0.48 ± 0.01	0.51 ± 0.03	0.86 ± 0.06	0.88 ± 0.03^{a}	0.37 ± 0.01^{aB}	0.44 ± 0.04^{aA}	0.32 ± 0.02^{aB}	0.38 ± 0.05^{aA}

All values are mean±SD of three replicates.

[1)]Treatments: Control, meat batter formulated without silkworm pupae powder and TG; T1, meat batter formulated with 5% silkworm pupae powder; T2, meat batter formulated with 10% silkworm pupae powder; T3, meat batter formulated with 15% silkworm pupae powder.

[a-d]Means with different superscripts within a same column differ significantly ($p<0.05$).

[A,B]Indicate significant differences in average scores among groups compared ($p<0.05$).

patties added with 10% mealworm powder have higher hardness, chewiness, and gumminess values than control patties (Kim *et al.*, 2015). These values are increased as mealworm addition level is increased (Kim *et al.*, 2015). Kim *et al*. (2016) have reported that emulsion sausages added with silkworm pupae and mealworm have higher hardness values than control sausages due to reduced moisture contents after the addition of edible insects. Meat batter added with 15% silkworm pupae (T3) had higher texture properties than control batter due to its lower moisture content. This result is in agreement with that of Lin *et al.* (2000) showing that the low moisture content of soy protein meat has resulted in hard texture. Hard texture of meat batter could be due to reduced cooking loss. Many researchers have shown that meat products with decreased cooking loss have high values of hardness (Choi *et al*., 2012; Pietrasik and Duda, 2000). Incorporation of TG into meat batter significantly improved its texture properties except springiness. These results were in agreement with those of Lee and Chin (2009) reporting that the hardness, gumminess, and chewiness values of pork sausages added with TG were higher than those of control sausages. Cross-link with TG and proteins have also improved and maintained texture properties of foods (Motoki and Seguro, 1998). Choi *et al*. (2016) have shown that hardness of sausage is increased by the addition of TG. Atilgan and Kilic (2017) have shown that a combination of TG and additives can improve textural properties of ground meat. Non-meat proteins modified by TG can improve the breaking stress of sausage due to cross-linkage between TG and non-meat proteins (Muguruma *et al*., 2003). Rosell *et al*. (2003) have reported that 1% TG with lysine in protein can increase the extensibility of foods. Lysine content in silkworm pupae is 47.3-50.0 mg/g. It might be able to interact with TG and improve the bind ability of meat products (Rumpold and Schlüter, 2013). Intensive bonds between TG and silkworm pupae might have resulted in high TPA values in this study.

Conclusions

In the present study, silkworm pupae showed potential as a valuable additive for meat products. The addition of silkworm pupae increased nutrition values such as protein, fat, and ash contents but reduced the cooking loss of meat batter. Insufficient binding ability of silkworm pupae containing meat batter was improved by the addition of TG. Meat batter containing silkworm pupae and TG showed increased pH, viscosity, and texture properties compared to the control. Further studies are needed to determine the effect of silkworm pupae as a meat replacement in meat products.

References

1. AOAC. (1995) Official methods of analysis of AOAC (Vol. 41, 16th ed.) Association of Official Analytical Chemists, Washington, DC.
2. Assielou, B., Due, E. A., Koffi, M. D., Dabonne, S., and Kouame, P. L. (2015) *Oryctes owariensis* larvae as good alternative protein source: Nutritional and functional properties. *Ann. Res. Rev. Biol.* **8**, 1-9.
3. Atilgan, E. and Kilic, B. (2017) Effects of microbial transglutaminase, fibrimex and alginate on physicochemical properties of cooked ground meat with reduced salt level. *J. Food Sci. Technol.* **54**, 303-312.
4. Baker, M. A., Shin, J. T., and Kim, Y. W. (2016) An exploration and investigation of edible insect consumption: The impacts of image and description on risk perceptions and purchase intent. *Psychol. Mark*. **33**, 94-112.
5. Bourne, M. C. (2002) Food Texture and Viscosity: Concept and Measurement (2nd ed.). New York: Academic Press.

6. Chin, K. B., Go, M. Y., and Xiong, Y. L. (2009) Konjac flour improved textural and water retention properties of transglutaminase-mediated, heat-induced porcine myofibrillar protein gel: Effect of salt level and transglutaminase incubation. *Meat Sci*. **81**, 565-572.
7. Choe, J. H., Kim, H. Y., Lee, J. M., Kim, Y. J., and Kim, C. J. (2013) Quality of frankfurter-type sausages with added pig skin and wheat fiber mixture as fat replacers. *Meat Sci*. **93**, 849-854.
8. Choi, Y. S., Choi, J. H., Han, D. J., Kim, H. Y., Kim, H. W., Lee, M. A., Chung, H. J., and Kim, C. J. (2012) Effects of *Laminaria japonica* on the physico-chemical and sensory characteristics of reduced-fat pork patties. *Meat Sci.* **91**, 1-7.
9. Choi, Y. S., Jeon, K. H., Park, J. D., Sung, J. M., Seo, D. H., Ku, S. K., Oh, N. S., and Kim, Y. B. (2015) Comparison of pork patty quality characteristics with various binding agents. *Korean J. Food Cook. Sci.* **31**, 588-595.
10. Choi, Y. S., Jeong, T. J., Kim, H. W., Hwang, K. E., Sung, J. M., Seo, D. H., Kim, Y. B., and Kim, C. J. (2016) Combined effects of sea mustard and transglutaminase on the quality characteristics of reduced-salt frankfurters. *J. Food Process. Preserv.* DOI:10.1111/jfpp.12945
11. Dimitrakopoulou, M. A., Ambrosiadis, J. A., Zetou, F. K., and Bloukas, J. G. (2005) Effect of salt and transglutaminase (TG) level and processing conditions on quality characteristics of phosphate-free, cooked, restructured pork shoulder. *Meat Sci*. **70**, 743-749.
12. Gujral, H. S. and Rosell, C. M. (2004) Functionality of rice flour modified with a microbial transglutaminase. *J. Cereal Sci.* **39**, 225-230.
13. Herrero, A. M., Carmona, P., Cofrades, S., and Jiménez-Colmenero, F. (2008) Raman spectroscopic determination of structural changes in meat batters upon soy protein addition and heat treatment. *Food Res. Int.* **41**, 765-772.
14. Hong, G. P., Min, S. G., and Chin, K. B. (2012) Emulsion properties of pork myofibrillar protein in combination with microbial transglutaminase and calcium alginate under various pH conditions. *Meat Sci*. **90**, 185-193.
15. Hwang, S. Y. and Choi, S. K. (2015) Quality characteristics of muffins containing mealworm (*Tenebrio molitor*). *Korean J. Culinary Res*. **21**, 104-115.
16. Ionescu, A., Aprodu, I., Darabă, A., and Porneală, L. (2008) The effects of transglutaminase on the functional properties of the myofibrillar protein concentrate obtained from beef heart. *Meat Sci*. **79**, 278-284.
17. Jeon, J. R. and Park, J. R. (1992) Functional properties of silkworm larvae protein concentrate after enzyme treatments. *J. Korean Soc. Food Sci. Nutr.* **21**, 706-711.
18. Kim, H. M., Kim, J. N., Kim, J. S., Jeong, M. Y., Yun, E. Y., Hwang, J. S., and Kim, A. J. (2015) Quality characteristics of patty prepared with mealworm powder. *Korean J. Food Nutr.* **28**, 813-820.
19. Kim, H. W., Setyabrata, D., Lee, Y. J., Jones, O. G., and Kim, Y. H. B. (2016) Pre-treated mealworm larvae and silkworm pupae as a novel protein ingredient in emulsion sausages. *Innov. Food Sci. Emerg. Technol.* **38**, 116-123.
20. Kim, H. Y., Lee, E. S., Jeong, J. Y., Choi, J. H., Choi, Y. S., Han, D. J., Lee, M. A, Kim, S. Y., and Kim, C. J. (2010) Effect of bamboo salt on the physicochemical properties of meat emulsion systems. *Meat Sci*. **86**, 960-965.
21. Kim, I. S., Jin, S. K., Jo, C. U., Lee, M. H., and Jang, A. R. (2008) Quality characteristics of pork patties containing silkworm powder and vegetable worm (*Paecilomyces japonica*) during cold storage. *Korean J. Food Sci. Anim. Resour.* **28**, 521-528.
22. Kim, S. H., Kim, K. B., Noh, J. S., Yun, E. Y., and Choi, S. K. (2014) Quality characteristics of pasta with addition of mealworm (*Tenebrio molitor*). *Food Serv. Ind. J.* **10**, 55-64.
23. Kinyuru, J. N., Kenji, G. M., and Njoroge, M. S. (2009) Process development, nutrition and sensory qualities of wheat buns enriched with edible termites (*Macrotermes subhylanus*) from Lake Victoria region, Kenya. *AJFAND*. **9**, 1739-1750.
24. Lee, H. C. and Chin., K. B. (2009) Effect of transglutaminase, acorn, and mungbean powder on quality characteristics of low-fat/salt pork model sausages. *Korean J. Food Sci.* **29**, 374-381.
25. Lin, S., Huff, H. E., and Hsieh, F. (2000) Texture and chemical characteristics of soy protein meat analog extruded at high moisture. *J. Food Sci*. **65**, 264-269.
26. Meiying, Z., Guocheng, D., and Jian, C. (2002) pH control strategy of batch microbial transglutaminase production with Streptoverticillium mobaraense. *Enzyme Microb. Technol.* **31**, 477-481.
27. Min, K. T., Kang, M. S., Kim, M. J., Lee, S. H., Han, J. S., and Kim, A. J. (2016) Manufacture and quality evaluation of cookies prepared with mealworm (*Tenebrio molitor*) powder. *Korean J. Food Nutr.* **29**, 12-18.
28. Motoki, M. and Seguro, K. (1998) Transglutaminase and its use for food processing. *Trends Food Sci. Technol.* **9**, 204-210.
29. Muguruma, M., Tsuruoka, K., Katayama, K., Erwanto, Y., Kawahara, S., Yamauchi, K., Sathe, S. K., and Soeda, T. (2003) Soybean and milk proteins modified by transglutaminase improves chicken sausage texture even at reduced levels of phosphate. *Meat Sci.* **63**, 191-197.
30. Nowak, V., Persijn, D., Rittenschober, D., and Charrondiere, U. R. (2016) Review of food composition data for edible insects. *Food Chem.* **193**, 39-46.
31. Park, G. S. and Park, J. R. (1986) Functional properties of silkworm larvae protein concentrate. *Korean J. Food Sci. Technol*. **18**, 204-209.
32. Pietrasik, Z. and Duda, Z. (2000) Effect of fat content and soy protein/carrageenan mix on the quality characteristics of comminuted, scalded sausages. *Meat Sci.* **56**, 181-188.
33. Pietrasik, Z., Jarmoluk, A., and Shand, P. J. (2007) Effect of non-meat proteins on hydration and textural properties of pork meat gels enhanced with microbial transglutaminase. *LWT-Food Sci. Technol.* **40**, 915-920.
34. Rosell, C. M., Wang, J., Aja, S., Bean, S., and Lookhart, G. (2003) Wheat flour proteins as affected by transglutaminase and glucose oxidase. *Cereal Chem.* **80**, 52-55.
35. Rumpold, B. A. and Schlüter, O. K. (2013) Potential and chal-

lenges of insects as an innovative source for food and feed production. *Innov. Food Sci. Emerg. Technol.* **17**, 1-11.
36. Sah, L. P. and Jung, C. E. (2012) Global perspective of edible insects as human food. *Korean J. Soil Zool.* **16**, 1-8.
37. Steenkamp, J. B. E. and van Trijp, H. (1996) Quality guidance: A consumer-based approach to food quality improvement using partial least squares. *Eur. Rev. Agric. Econ.* **23**, 195-215.
38. Stevenson, C. D., Dykstra, M. J., and Lanier, T. C. (2013) Capillary pressure as related to water holding in polyacrylamide and chicken protein gels. *J. Food Sci.* **78**, 145-151.
39. Sugumaran, M. (2002) Comparative biochemistry of eumelanogenesis and the protective roles of phenoloxidase and melanin in insects. *Pigm. Cell Res.* **15**, 2-9.
40. Tan, H. S. G., Verbaan, Y. T., and Stieger, M. (2016) How will better products improve the sensory-liking and willingness to buy insect-based foods? *Food Res. Int.* **92**, 95-105.
41. Tseng, T. F., Liu, D. C., and Chen, M. T. (2000) Evaluation of transglutaminase on the quality of low-salt chicken meat-balls. *Meat Sci.* **55**, 427-431.
42. Zhou, J. and Han, D. (2006) Proximate, amino acid and mineral composition of pupae of the silkworm *Antheraea pernyi* in China. *J. Food Compost. Anal.* **19**, 850-853.
43. Zorba, O., Kurt, S., and Gençcelep, H. (2005) The effects of different levels of skim milk powder and whey powder on apparent yield stress and density of different meat emulsions. *Food Hydrocoll.* **19**, 149-155.