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Comparing the effects of different additives on the physicochemical and textural characteristics of pork batter

Abstract

This study aimed to compare the effects of different additives on the physicochemical and textural characteristics of pork batter (uncooked emulsion). Different concentrations (0.5%, 1.0%, and 1.5%) of three additives, namely, soy protein isolate (SPI), sodium caseinate (SC), and blood plasma (BP), were added to pork meat and excluded from the control. These additives decreased pH in the following order of magnitude: BP > SC > SPI. The addition of BP to pork emulsion elicited higher lightness and hue values, but a lower redness value than SPI or SC. Texture properties did not differ significantly between the control and additive-treated emulsions. Meanwhile, BP caused an increase shear force and gumminess and improved emulsion stability. Overall, BP is a suitable emulsion stabilizer compared with SPI or SC. Further, this study's findings provide insight into the potential use of plasma proteins from slaughter blood as binders in the eco-friendly production of high-quality meat products.

Keywords: pork emulsion, blood plasma, soy protein isolate, sodium caseinate, emulsion stability

Introduction

Various non-meat ingredients are included in manufactured meat products to provide various functions throughout the production, marketing, and consumption processes (Mills, 2024). These ingredients, such as salt, sugar, vegetable proteins (soy, chick peas, and lupine), sodium caseinate (SC), starch, pectin, gelatin, gum, sodium phosphate, ascorbic acid, potassium sorbate, and natural extracts, are mostly used to modify or enhance flavor and provide preservation (Ianiţchi et al., 2023; Woo et al., 2024; Jeong & Yang, 2023). Other functions of these ingredients include color stabilization; preservation; improving texture properties such as hardness, tenderness, juiciness, cohesiveness, and springiness; and increasing water-binding capacity and emulsion stability (Bae et al., 2023; Ujilestari et al., 2023). Continued interest in understanding food production systems and food choices has stimulated exploration into meat product ingredients.

Emulsion stability in meat products is a critical factor that influences the overall quality, texture, and shelf-life of the product. Myosin and actomyosin are the main emulsifiers in meat products due to their high concentration and amphiphilic nature, which allows them to effectively stabilize oil-in-water emulsions by unfolding and orienting at the interface of lipid and aqueous phases. Salt, especially NaCl, solubilizes these meat proteins, allowing them to unfold and orient themselves to the lipid and aqueous phases, thus resulting in an oil-in-water emulsion (Schilling, 2019). Emulsions are stabilized via protein coagulation during thermal processing; in addition to salt, emulsion products commonly use ingredients such as phosphates, nitrite, dextrose, and binders (Lee et al., 2023). Binders, such as SC, soy proteins, whey protein, egg white, and fiber, are commonly used to enhance emulsion stability (Kim et al., 2017; Schilling, 2019). SC, which is used as an emulsifier and emulsion stabilizer, is water soluble and indirectly improves water binding and contributes less off-flavor. Soy protein isolate (SPI) is used for water and fat binding as well as emulsion stabilization in meat products; it is also valuable because of its high protein content (Chempaka et al., 1996).

The disposal of most slaughter blood poses environmental challenges due to wastewater costs and pollution, making the utilization of blood plasma proteins including fibrinogen, albumin, and globulins in food production an ecofriendly alternative. Blood plasma (BP) can be utilized in the food industry as a valuable ingredient owing to its ability to create gels, emulsify, and produce foam (Jin et al., 2021; Toldrá et al., 2012). BP proteins are potentially useful as natural emulsifiers, stabilizers, and color additives in meat products, especially emulsion-type pork sausages (Kim et al., 2017). Some studies have reported that meat products can utilize porcine plasma instead of polyphosphates and caseinate (Hurtado et al., 2011; Sònia Hurtado et al., 2012). However, although certain additives improve the quality of meat products, comparing the effects of additives on pork batter is imperative. Therefore, this study aimed to compare the effects of three different additives (soy protein isolate, sodium caseinate, and blood plasma) as emulsifiers and stabilizers on pork batter in terms of its physicochemical and textural characteristics to contribute producing for meat products with high quality.

Materials and Methods

Materials

SPI and SC were purchased from Dongbang FoodMaster Co., Ltd. (Eumseong, Korea). Whole porcine blood and backfat were acquired from a local slaughterhouse. Ethylenediaminetetraacetic acid (EDTA) was purchased from Sigma-Aldrich (St. Louis, MO, USA). Fibrous casings were obtained from Kalle GmbH (Wiesbaden, Germany).

Preparation of Pork Batter`

To prepare plasma, 1 L of whole porcine blood was added to 2 g of EDTA. The mixed blood samples were centrifuged at 8,000 g for 15 min at 4 ℃. Thereafter, the obtained BP was stored at –50 ℃. Fresh leg of pork and backfat were diced and ground to 5-mm-diameter using a mincer. Pork emulsions were prepared according to the formula presented in Table 1. The basic ingredients of the pork emulsion were as follows: 72.4% meat, 11.2% backfat, 14.9% ice, and 1.5% refined salt. The following samples were prepared: T1 (commercial pork emulsion), T2 (0.5% SPI), T3 (1.0 % SPI), T4 (1.5% SPI), T5 (0.5% SC), T6 (1.0% SC), T7 (1.5% SC), T8 (0.5% BP), T9 (1.0 % BP), and T10 (1.5% BP). The minced meat was ground for 1 min using a bowl cutter; subsequently, half of the ice, 1.5% refined salt, and an additive (SPI, SC, or BP) were mixed for 2 min. Thereafter, fat was added and emulsified for 1 min, and the remaining half of the ice was placed in a batter and further mixed at a high speed (bowl speed: 24 rpm; knife shaft speed: 2,840 rpm) for 3 min to obtain emulsion batters. The emulsified batters were subsequently stuffed into fibrous casings (70-mm diameter) using a stuffer (IS-8, Sirman, Italy) and cooked in a cooking chamber (Thematec

Food Industry Co., Ltd., Korea) until the internal temperature reached 75 °C. After cooling, the samples were stored at 4 °C for further analysis.

Physicochemical Characteristics

pH

Cooked emulsion samples (5 g) and 45 mL of distilled water were mixed and homogenized using a homogenizer (T25B, IKA Sdn, Bhd., Malaysia) to produce a slurry. The pH of the cooked emulsion samples was determined using a pH meter (Mettler Toledo, Switzerland).

Color

The colors (CIE: lightness [L*], redness [a*], and yellowness [b*]) of the cooked emulsion samples were evaluated using a Minolta colorimeter (CR-400, Japan) that had been calibrated with a white plate (Y=93.5, X=0.3132, y=0.3198). The whiteness (W) value was calculated using the following formula: L*–3b*. The chroma value (C*) and hue angle were calculated as follows: (a*2+b*2) 1/2 and Tan–1(b*/a*), respectively (Fernández–López et al., 2000). The colors were evaluated five times on the cut surface of each sample (thickness: 12–15 mm).

Emulsion Stability

Emulsion stability was measured using a method described previously, with modifications (Serdaroglu & Ozsumer, 2003). Emulsified pork batter samples were placed in pre-weighed 50-mL centrifuge tubes and centrifuged at 3,000 × g for 2 min at 4 °C. Each tube was heated in a water bath for 30 min until reaching 75±1℃, cooled to 4±1℃, weighed, transferred to a pre-weighed crucible, and dried for 16 h. Total loss (%) was measured based on the total fluid released from the centrifuged pork batter, and moisture (%) and fat (%) loss were evaluated based on the magnitude of the total loss. These emulsion stability-related factors were calculated as follows:

· Total loss (%) = total fluid released by sample weight × 100

· Water loss (%) = (weight of crucible + total fluid released)–(weight of dried crucible) × 100

· Fat loss (%) = 100–water loss (%)

Analysis of Texture Properties

The shear force of each sample was estimated using an Instron 3343 tensiometer (US/MX50, A&D Co., Ltd., USA) attached to a Warner–Bratzler shearing device, providing a 100-mm/min crosshead speed. Five cores (2×2×1 cm) of each emulsion were analyzed at a crosshead speed of 100 mm/min. A texture analyzer (TA-XTZ-5, Shimadzu Co., Japan) was employed under the following conditions: a 5-mm-diameter cylindrical plunger, 60-mm/min depression speed, and 500-N load cell. Texture property analysis of each sample was replicated five times.

Statistical analysis

Statistical analysis was performed using the PROC MIXED procedure of SAS (SAS Institute Inc., Cary, NC). All data were carried out using a completely randomized design. Each replicate was considered as the experimental unit for all analyses. Outlier data were checked using the UNIVARIATE procedure of SAS (Steel et al., 1997). The LSMEANS procedure was used to calculate treatment means and the PDIFF option of SAS was used to separate the means if the difference was significant. The effects of different additives were compared with those of control based on the contrast test. In addition, the effects of additional SPI and SC were also than those of BP based on the contrast test. Orthogonal polynomial contrast tests were also performed to verify the linear and quadratic effect of increasing inclusion levels of SPI, SC, and BP. Significance for statistical test was considered at $p<0.05$.

Results and Discussion

Comparison of Physicochemical Characteristics on Pork Batter with Different Additives

The physicochemical characteristics, including pH and CIE color (L*, a*, b*, W, C, and h) values, of pork emulsions with the different additives (SPI, SC, and BP) at varied concentrations (0.5, 1.0 and 2.0 g) are compared in Table 2. The pork emulsion pH values of the different additive treatments (T2–T10) significantly decreased compared with that of T1 (the control, $p<0.05$). Among the treatments, pH significantly decreased in the following order of magnitude: SPI > SC > BP; in addition, pH decreased with increasing additive levels (linear and quadratic, $p<0.01$).

The pH value of meat products depends on the inherent pH of the raw meat and any included additives, which in turn can influence various physical and chemical properties, such as meat color, texture, water-holding capacity, and gel stability (Puolanne et al., 2001). Dàvila et al. (2007) reported that the addition of porcine BP (2 g/100 g) and SC to pork gel was affected by pH, especially that in the 5.3–6.2 range, influencing water-holding capacity via gel formation-related protein aggregation (Dàvila et al., 2007). In addition, the viscosity of the BP-added emulsion at pH 6.5 and 7.0 was significantly greater than that at pH 5.0. At high pH levels, SPI addition resulted in the formation of more disulfide-mediated aggregates, leading to tertiary structure loss and reduced solubility. In contrast, SPI at pH 6 displayed better storage stability than at other pH levels (Guo et al., 2020). This study also revealed that within a pH range of 6.2–6.6, the different additives potentially enhanced emulsion stability and texture properties.

The pork emulsion L* values of the different additive treatments (T2–T10) significantly decreased ($p<0.001$) compared with that of T1 (control). Further, the L* values of the pork emulsions significantly increased in the following order of magnitude: BP > SC > SPI; in addition, these values increased with increasing SPI and SC levels (quadratic association, $p<0.01$). However, L* was not influenced by increasing BP levels in pork emulsion. The pork emulsion a* values of T2–T10 significantly decreased ($p<0.001$) compared with that of T1. Moreover, the a* values of the pork emulsions significantly increased in the following order of magnitude: SPI > SC > BP; in addition, these values increased with increasing SC levels (linear and quadratic, $p<0.05$). The redness of the pork emulsions increased with increasing BP level (quadratic association, $p<0.01$) but was not influenced by SPI level. The pork emulsion b* values of T2–T10 significantly increased ($p<0.001$) compared with that of T1. The yellowness of the pork emulsions significantly increased in the following order of magnitude: SPI > SC > BP. Significant differences were noted upon increasing SPI and BP addition levels; nonetheless, no significant difference was observed after SC addition. The pork emulsion W values of T2–T10 significantly decreased ($p<0.001$) compared with that of T1. No significant differences in whiteness were noted among the different additive treatments. A quadratic increase ($p<0.05$) in the pork emulsion W values occurred with SC and BP level increases of 40.67–42.99 and 38.40–43.82, respectively; however, increasing the SPI level of the pork emulsions decreased their W values (linear and quadratic, $p<0.05$). The pork emulsion C* values of T2–10 were significantly lower than that of T1 ($p<0.001$). Further, no significant differences in C* values were observed after SPI and BP addition; nevertheless, C* significantly decreased with SC addition ($p<0.01$). The C* values of the pork emulsions significantly increased with increasing SPI level (linear and quadratic, $p<0.01$); however, these values significantly decreased with increasing BP level (quadratic association, $p<0.001$). The hue angle of the pork emulsions significantly increased in T2–T10) ($p<0.001$) compared with that in T1. Moreover, it significantly increased in the following order of magnitude: BP > SC > SPI; in addition, it exhibited a linear and quadratic increase ($p<0.05$) with SPI and SC level increases of 68.73–69.98 and 70.13–70.41, respectively. Blood plasma influence the pH and water holding capacity in food products (Polo et al., 2009; Silva et al., 2003), especially the pH alteration and improved water holding capacity affect color stability and the overall appearance (Qiao et al., 2001). Thus, the addition of BP can attribute to enhance the color intensity, leading to an increased hue angle.

Non-meat ingredients are typically used in meat products to enhance color or influence color variation. This study’s results are not entirely consistent with those of Cofrades et al. (2000), who found an increase in plasma protein addition level (0–5%) to significantly increase lightness and yellowness in pork sausage (Cofrades, Guerra, Carballo, Fernández-Martín, & Colmenero, 2000). In addition, soy protein concentrate has been found to provide protection against oxymyoglobin oxidation, which leads to metmyoglobin having a brown color compared with that of the control (Wanasundara & Pegg, 2007). Moreover, BP proteins in emulsion-type pork sausage have been found to exhibit reduced lightness (Soriano, Torres, & Ramos, 1997). Meat color changes are presumably induced by raw material fibers in meat products, according to previous studies (Claus & Hunt, 1991; Troutt et al., 1992). In a prior study, Turkish meatballs with various inclusion levels (5, 10, 15, and 20%) of dietary fiber yielded higher b* values (Yasarlar et al., 2007). Notwithstanding, this study could not clearly establish relationships between the three additives and color parameters; hence, further studies are required to compare and analyze potential factors influencing meat color parameters in non-meat proteins.

Comparison of the Effects of Different Additives on the Emulsion Stability and Textural Characteristics of Pork Batter

The emulsion stability of the pork emulsions after adding the different additives (SPI, SC, and BP) at varying concentrations (0.5, 1.0, and 2.0 g) are compared in Table 3. On comparing emulsion stability between T1 and T2–T10, total and moisture loss were lower ($p<0.01$) in the additive-treated groups than in the control, indicating superior stability. However, fat loss was higher ($p<0.01$) in the additive-treated groups, indicating decreased stability. Protein extracts isolated from meat have been found to stabilize O/W emulsions at pH 3–11 (Li et al., 2020). SPI has two main components: 7 S (β-conglycinin) and 11 S (glycinin), both possessing emulsifying properties (Peng et al., 2020). SPIs are amphiphilic in nature, enabling them to play important an role in thickening and surfactivity, thus forming stable O/W emulsions (Lu et al., 2017). SC is a commercial product obtained from milk casein aggregates, and it serves as an excellent emulsifier in O/W interfaces because of its amphiphilic nature (Zhou et al., 2022). Additionally, SC comprises two proteins, namely, αs1-casein and β-casein, which can induce the formation of a stable emulsion by covering fat globules (Dickinson et al., 1998). The significantly high solubility of SC has been observed at pH 7.0–8.0 (Duare et al., 1998). Amphiphilic structures possess hydrophilic main chains with a small amount of branched hydrophobic chains. The presence of hydrophobic groups enables the amphiphilic polymers to reduce the interfacial tension between oil and water, resulting in the effective emulsification of oil (Abidin et al., 2012). Additionally, intermolecular hydrophobic interactions among the polymers lead to the formation of a network structure, significantly increasing the viscosity of the amphiphilic polymers (Lu et al., 2017). BP can also be used as an emulsifier or fat replacer in meat products. Bovine BP has demonstrated considerable hydrophobicity and a high emulsifying activity index at pH 3.0 and 7.0, respectively (Silva & Silvestre, 2003). The viscosity of a porcine plasma protein-stabilized gel-like emulsion at pH 6.5 and 7.0 was found to be significantly higher than that at pH 5.0 ($p<0.05$); in addition, after 48-h storage, the emulsion exhibited stability higher than 91.07% (Li et al., 2017). On comparing emulsion stability among the three different additives, BP, SC, and SPI exhibited superior stability in that order. In particular, total loss decreased as additive level increased (linear and quadratic, $p<0.01$), suggesting an influence on stability enhancement. Moisture loss was only reduced (linear and quadratic, $p<0.01$) by BP, confirming its impact on stability. Thus, these observations indicate that the amphiphilic structures and emulsifying activities of the three additives can induce high emulsion stability, and the effects of additives on emulsion stability may be influenced by pH.

Shear force is an indicator influenced by tenderness, affecting texture characteristics. It was significantly higher in all additive-treated groups than in the control group (Table 3). On comparing the additives, BP and SC exhibited significantly higher shear force than SPI. However, no significant differences in shear force were noted among the additive-treated groups based on treatment level.

The textural characteristics (including hardness, cohesiveness, springiness, gumminess, chewiness, and adhesiveness) and tenderness of the pork emulsions treated with the different additives (SPI, SC, and BP) at varied concentrations (0.5, 1.0, and 2.0 g) are compared in Table 3. All textural characteristics did not display significant differences between the treatments (T2–T10) and control (T1). Moreover, the gumminess of the pork emulsions significantly increased ($p<0.05$) after BP and SPI addition compared with that after SC addition; however, no significant difference in other textural characteristics was observed among treatments with different additives (T2–T10). Furthermore, hardness significantly increased with increasing SPI levels. Comprehensively, among the three additives, BP notably influenced shear force and gumminess. The structural characteristics of heat-treated plasma protein gels have been found to impact the hardness strengthening effect in the pH range of 5.0–7.0 (Li et al., 2017).

Previous research has also demonstrated that adding plasma protein at a concentration of 1 g/100 g or higher significantly increases the mechanical force and binding strength of ground beef (Seideman et al., 1979; Suter et al., 1976). Wang et al (2023) also concluded that plasma protein improved the gumminess of restructured ground chicken patty (Wang et al., 2023). Hydrophilic amino acids in plasma proteins facilitate their involvement in the gelation process alongside salt-soluble proteins, such as myosin and troponin (Bai et al., 2020; Gao et al., 2023). Moreover, the structure of myofibrillar and plasma proteins tends to unfold, enhancing their ability to interact under the influence of ultrasound. Plasma proteins also serve a crucial role in modifying the unique structure of myofibrillar proteins (Wang et al., 2023). Consequently, BP addition in this study resulted in the formation of a more stable protein structure in the emulsion, potentially enhancing texture properties. Consequently, relative differences were noted among the additives in certain texture properties; however, the other texture properties did not significantly differ among the additives. Thus, compare the texture properties of SPI, SC, and BP in the pork emulsion samples.

Conclusion

The findings of this study demonstrate that the three non-meat additives had a significant impact on improving the quality of pork batter emulsions. Additive-treated pork emulsion exhibited lower pH, lightness, redness, and whiteness values, while showing increased yellowness, chroma, and hue levels. Moreover, the three additives decreased pH in the pork emulsions, and pH level may influence water-holding capacity via gel formation-related protein aggregation. Emulsion stability was also improved, with BP showing the highest stability compared to SPI and SC. Although most textural properties remained similar between the control and treated samples, BP led to an increase in shear force and gumminess. These results suggest that BP can be effectively utilized as a stabilizer or binding agent in meat product development. Furthermore, this study provides valuable insights into the potential application of by-products as value-added ingredients in the meat industry, contributing foundational data for future research on the utilization of such by-products.

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Table 1. Composition of additive-treated pork emulsions

Treatment	Ingredients (g)							Total
	Pork	Fat	Water	Salt	Additives			
					SPI	SC	BP	
T1	72.4	11.2	14.9	1.5	-	-	-	100
T2	71.9	11.2	14.9	1.5	0.5	-	-	100
T3	71.4	11.2	14.9	1.5	1.0	-	-	100
T4	70.4	11.2	14.9	1.5	2.0	-	-	100
T5	71.9	11.2	14.9	1.5	-	0.5	-	100
T6	71.4	11.2	14.9	1.5	-	1.0	-	100
T7	70.4	11.2	14.9	1.5	-	2.0	-	100
T8	71.9	11.2	14.9	1.5	-	-	0.5	100
T9	71.4	11.2	14.9	1.5	-	-	1.0	100
T10	70.4	11.2	14.9	1.5	-	-	2.0	100

SPI: Soy protein isolated; SC: Sodium caseinate; BP: Porcine blood plasma

Table 2. Effects of the different additives on the physicochemical characteristics of the pork emulsions

Treatment	Additives	Addition level (%)	Physicochemical characteristics						
			pH	CIE color					
				L	a	b	W	C	h
T1	-	-	6.65	75.81	4.46	10.86	43.22	11.74	67.69
T2	Soy protein isolated (SPI)	0.5	6.53	74.98	4.27	11.97	42.07	11.77	68.73
T3		1.0	6.34	74.50	4.63	11.45	40.15	12.35	67.98
T4		1.5	6.23	75.63	4.23	11.62	40.77	12.37	69.98
T5	Sodium caseinate (SC)	0.5	6.40	75.14	4.15	11.49	40.67	12.22	70.13
T6		1.0	6.26	74.77	4.49	11.11	41.42	11.99	67.97
T7		1.5	6.21	76.15	3.93	11.05	42.99	11.73	70.41
T8	Blood plasma (BP)	0.5	6.17	75.48	3.64	12.36	38.40	12.89	73.57
T9		1.0	6.08	75.41	4.14	11.43	41.12	12.16	70.07
T10		1.5	6.27	76.49	4.42	10.89	43.82	11.75	67.89
SEM			0.04	0.22	0.06	0.10	0.45	0.10	0.29
P-value									
Contrast									
CON vs. Additives			<0.001	0.006	<0.001	<0.001	<0.001	<0.001	<0.001
BP vs. SPI			<0.001	<0.001	<0.001	0.013	0.755	0.216	<0.001
BP vs. SC			<0.001	0.016	0.019	<0.001	0.122	0.001	0.001
SPI level (linear)[2)]			<0.001	0.369	0.180	<0.001	0.005	0.002	<0.001

SPI level (quadratic)[2)]	<0.001	0.001	0.122	<0.001	<0.001	0.005	0.002
SC level (linear)[2)]	<0.001	0.447	0.001	0.353	0.749	0.867	0.005
SC level (quadratic)[2)]	<0.001	0.004	0.007	0.101	0.022	0.099	0.018
BP level (linear)[2)]	0.003	0.247	0.743	0.742	0.986	0.774	0.707
BP level (quadratic)[2)]	<0.001	0.065	<0.001	<0.001	<0.001	<0.001	<0.001

[1)] Data are Means ± SEM of 15 and 5 replicates for the CON treatment and other treatments, respectively.

[2)] P- values for the linear (L) and quadratic (Q) effects.

L, lightness; a, redness; b, yellowness; W, whiteness (W = L – 3b); C, chroma; h, hue value.

Table 3. Effects of the different additives on the emulsion stability of the pork emulsions

Treatment	Additives	Addition level (%)	Emulsion stability (%)		
			Total loss	Moisture loss	Fat loss
T1	-	-	25.03	93.50	6.50
T2	Soy protein isolated (SPI)	0.5	25.80	93.26	6.74
T3		1.0	23.83	93.85	6.14
T4		1.5	19.12	93.20	6.80
T5	Sodium caseinate (SC)	0.5	25.25	93.17	6.83
T6		1.0	25.19	93.70	6.30
T7		1.5	17.77	93.02	6.98
T8	Blood plasma (BP)	0.5	22.81	92.69	7.31
T9		1.0	24.77	93.04	6.96
T10		1.5	16.41	92.60	7.40
SEM			0.66	0.16	0.16
P-value					
Contrast					
CON vs. Additives			<0.001	0.004	0.004
BP vs. SPI			0.005	<0.001	<0.001
BP vs. SC			0.013	<0.001	<0.001
SPI level (linear)[2]			<0.001	0.124	0.124
SPI level (quadratic)[2]			<0.001	0.236	0.236
SC level (linear)[2]			0.001	0.511	0.511
SC level (quadratic)[2]			<0.001	0.802	0.802
BP level (linear)[2]			<0.001	0.006	0.006
BP level (quadratic)[2]			<0.001	0.004	0.004

[1] Data are Means ± SEM of 15 and 5 replicates for the CON treatment and other treatments, respectively.

[2] P-values for the linear (L) and quadratic (Q) effects.

Table 4. Effects of the different additives on the tenderness and textural characteristics of the pork emulsions

Treatment	Additives	Addition level (%)	Textural properties						
			Shear force (kg)	Hardness (kg)	Cohesiveness (%)	Springiness (mm)	Gumminess (kg)	Chewiness (kg,mm)	Adhesiveness (kg s)
T1	-	-	2.12	0.21	0.60	1.03	0.12	0.12	0.11
T2	Soy protein isolated (SPI)	0.5	2.52	0.22	0.52	1.03	0.12	0.12	0.10
T3		1.0	1.86	0.23	0.57	1.00	0.13	0.13	0.11
T4		1.5	2.09	0.23	0.61	1.07	0.14	0.16	0.11
T5	Sodium caseinate (SC)	0.5	2.92	0.21	0.53	1.00	0.11	0.11	0.10
T6		1.0	2.12	0.23	0.56	1.00	0.13	0.13	0.12
T7		1.5	2.12	0.19	0.55	1.02	0.11	0.11	0.10
T8	Blood plasma (BP)	0.5	2.85	0.20	0.54	1.00	0.11	0.11	0.10
T9		1.0	2.25	0.25	0.64	1.05	0.16	0.17	0.13
T10		1.5	2.21	0.22	0.60	1.02	0.13	0.13	0.12
SEM			0.04	0.07	0.03	0.03	0.01	0.01	0.01
P-value									
Contrast									
CON vs.			<0.001	1.86	0.202	0.670	0.357	0.535	0.487
Additives			<0.001	2.09	0.347	0.843	0.861	1.000	0.125
BP vs. SPI			<0.001	2.92	0.063	0.464	0.027	0.056	0.067
BP vs. SC			<0.001	2.12	0.302	0.192	0.011	0.021	0.823
SPI level			<0.001	2.12	0.127	0.235	0.027	0.041	0.969
(linear)[2)]			<0.001	2.85	0.179	0.371	0.503	0.342	0.361
SPI level			<0.001	2.25	0.216	0.447	0.623	0.597	0.650
(quadratic)[2)]			0.003	2.21	0.915	0.444	0.069	0.073	0.116

SC level (linear)[2)] SC level (quadratic)[2)] BP level (linear)[2)] BP level (quadratic)[2)]	<0.001	0.07	0.830	0.471	0.075	0.102	0.257

[1)] Data are Means ± SEM of 27 and 9 replicates for the CON treatment and other treatments, respectively.

[2)] P-values for the linear (L) and quadratic (Q) effects.