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Physical properties of sausage analogues made with quinoa and cañihua flours, by extrusion

Propiedades físicas de análogos de salchicha elaborados con harinas de quinua y cañihua, mediante extrusión

Propriedades físicas de análogos de salsicha elaborados com farinhas de quinoa e cañihua, por extrusão

Jordan Deiby Aviles Leon*
Alicia M. Leon Tacca
Wenceslao T. Medina Espinoza

Escuela Profesional de Ingeniería Agroindustrial, Facultad de Ciencias Agrarias, Universidad Nacional del Altiplano de Puno, Perú.

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Abstract

Sausages are widely consumed meat products around the world. The objective of this research was to evaluate the physical properties (color, texture, cooking performance, diameter reduction) and acceptability of sausage analogues prepared from meat analogues using high-moisture extrusion. Two sausage analogues were prepared, including mixtures of quinoa flour (QF) and cañihua flour (KF) with soy protein isolate in different proportions, SA-1 (15 % QF, 15 % KF) and SA-2 (25 % QF, 15 % KF). Color was evaluated by image analysis, texture by texture profile analysis, cooking yield and diameter reduction by weight and dimension ratios. For comparison purposes, commercial chicken and pork sausages were used. SA-1 had a hardness of ~64 N, ~0.30 cohesiveness, ~0.65 elasticity and ~14 N chewiness, values similar to chicken sausages. The color of SA-1 and SA-2 was similar to chicken sausages, with a hue of ~318° and saturation between 12.54 and 15.89 %. The cooking yield of SA-1 was ~93 %, higher than that of commercial sausages (~86 %). Sensory evaluation of SA-1 was comparable to that of pork and chicken sausages. SA-1 had physical properties similar to commercial chicken sausages, demonstrating the possibility of producing this type of product.

*Corresponding author: javiles@est.unap.edu.pe

Resumen

Las salchichas son embutidos ampliamente consumidos en el mundo. El objetivo de la investigación fue evaluar las propiedades físicas (color, textura, rendimiento de cocción, reducción de diámetro) y la aceptabilidad de análogos de salchicha preparados a partir de análogos de carne, utilizando extrusión de alta humedad. Se elaboraron dos análogos de salchicha incluyendo en su formulación mezclas de harinas de quinua (QF) y de cañihua (KF) con aislado proteico de soya, en diferentes proporciones, SA-1 (15 % QF, 15 % KF) y SA-2 (25 % QF, 15 % KF). El color se evaluó por análisis de imágenes, la textura mediante análisis de perfil de textura, el rendimiento de cocción y la reducción del diámetro con relaciones de peso y dimensión. Para efectos de comparación, se utilizaron salchichas comerciales de pollo y cerdo. Los SA-1, presentaron una dureza de ~64 N, ~0,30 cohesividad, ~0,65 elasticidad y ~14 N masticabilidad, valores semejantes a las salchichas de pollo. El color de SA-1 y SA-2 fue similar a las salchichas de pollo, tonalidad ~318 ° y saturación entre 12,54 a 15,89 %. El rendimiento de cocción de los SA-1 presentó un valor de ~93 %, mayor que el de las salchichas comerciales (~86 %). Sensorialmente, los SA-1 obtuvieron una evaluación comparable a la de las salchichas de cerdo y pollo. El SA-1 presentó propiedades físicas similares a las salchichas comerciales de pollo, demostrando la posibilidad de elaborar este tipo de productos.

Palabras clave: análogo de carne, aislado de proteína de soya, extrusión de alta humedad.

Resumo

As salsichas são enchidos amplamente consumidos em todo o mundo. O objetivo da pesquisa foi avaliar as propriedades físicas (cor, textura, rendimento na cozedura, redução do diâmetro) e a aceitabilidade de análogos de salsicha preparados a partir de análogos de carne, utilizando extrusão de alta umidade. Foram elaborados dois análogos de salsicha incluindo em sua formulação misturas de farinhas de quinoa (QF) e cañihua (KF) com isolado proteico de soja, em diferentes proporções, SA-1 (15 % QF, 15 % KF) e SA-2 (25 % QF, 15 % KF). A cor foi avaliada por análise de imagens; a textura por análise do perfil de textura; o rendimento de cozimento e a redução do diâmetro por relações de peso e dimensão. Para efeitos de comparação, foram utilizadas salsichas comerciais de frango e porco. As SA-1 apresentaram dureza de ~64 N, ~0,30 coesão, ~0,65 elasticidade e ~14 N mastigabilidade, valores semelhantes aos das salsichas de frango. A cor das SA-1 e SA-2 foi semelhante à das salsichas de frango, tonalidade ~318 ° e saturação entre 12,54 e 15,89 %. O rendimento de cozimento dos SA-1 apresentou um valor de ~93 %, superior ao das salsichas comerciais (~86 %). Sensorialmente, os SA-1 obtiveram uma avaliação comparável à das salsichas de porco e frango. O SA-1 apresentou propriedades físicas semelhantes às salsichas comerciais de frango, demonstrando a possibilidade de elaborar este tipo de produtos.

Palavras-chave: análogo de carne, isolado de proteína de soja, extrusão de alta umidade.

Introduction

Sausages are products generally made from minced red meat and fat, mixed with spices, additives, curing salt and antioxidants, which are stuffed into casings for processing, preservation and consumption (Bolívar-Monsalve *et al*., 2019; Flores and Piornos, 2021). Excessive consumption of red meat may be associated with health problems such as cardiovascular disease, obesity and even certain types of cancer due to its high content of fat, saturated fatty acids and cholesterol (Ferreira Corrêa *et al*., 2023; Ospina Meneses *et al*., 2011). Despite this, sausages are widely enjoyed in many parts of the world (Gutierrez-Varas and Siche, 2022).

Consumers are now more aware of the relationship between good nutrition and health (Meijer, 2025). In the specific case of meat, they are constantly searching for a healthy and tasty substitute (Ahmad *et al*., 2022). In line with this trend, the market has shifted its focus towards meat analogues made from plant-based ingredients such as soy protein isolate (SPI), using extrusion technology (Ozturk and Hamaker, 2023). These products are designed to replicate the qualities of conventional meat, such as texture, flavour and colour, as well as to modify nutritional properties (Kyriakopoulou *et al*., 2019).

The use of plant-based proteins in the preparation of meat analogues, opens up the possibility of including ancestral Andean crops such as quinoa (*Chenopodium quinoa* Willd) and cañihua (*Chenopodium pallidicaule* Aellen) in their formulations. Their incorporation would expand the range of ingredients available for analogue products, with a view to promoting and enhancing their use. These Andean crops have gained relevance in the food market, which demands high quality standards in raw materials, processes and final products (Hermann, 2009). Quinoa is a pseudocereal of great global importance due to its high nutritional value, as it provides significant amounts of protein, lipids, vitamins, minerals and essential amino acids such as lysine, methionine and cysteine (Bazile *et al*., 2021). Quinoa flour contains mainly starch and proteins, which give it a gelling capacity that favours the obtaining of attractive food textures (Wu and Guo, 2025). Cañihua, meanwhile, stands out for its high protein content (15-19 %) and its richness in lysine (5-6 %), isoleucine and tryptophan, with a lipid content of between 6 and 8 % and ash content of 3 to 4 %. It is also an important source of micronutrients such as iron and calcium (Bartolo, 2013; Fernández-López *et al*., 2021).

However, in the search for healthy and nutritious sausages made with meat analogues and new sources of vegetable protein, the physical properties of these new products must resemble those of conventional sausages as closely as possible. Therefore, the objective of this research was to evaluate the physical properties (colour, texture, cooking performance, diameter reduction) and sensory acceptability of a sausage analogue prepared from a meat analogue made with SPI, including quinoa and cañihua flours in its formulation, using high moisture extrusion (HME) technology.

Materials and methods

Materials

To formulate the sausage analogue, a meat analogue was used as the main ingredient, which includes mixtures of quinoa, cañihua and SPI flours in its formulation. The quinoa flour was obtained from Cooperativa Agroindustrial Cabana Ltda. in Puno, Peru, and the cañihua flour was obtained by grinding clean grains of the Cupi variety, purchased from Estación Experimental Agraria Illpa, Puno, Peru, in a pulverising mill (Fritsch, AS 200, Germany). The SPI was purchased from Shandong Kawah Oils Co., Ltd, China, with a protein content of 90 %. The flours and SPI were mixed and sieved through a 250 µm mesh (Retsch AS 200, Germany). For comparison purposes, commercial chicken and pork sausages purchased from a supermarket in the city of Puno were used.

Preparation of meat analogues

Considering the work of Sucasaca *et al*. (2025) and Zahari *et al*. (2020), who use SPI as the main ingredient, two meat analogues were produced, including mixtures of quinoa flour (QF) and cañihua flour (KF) with SPI in their formulation (Table 1).

Table 1. Codes of the formulations and proportions of the ingredients used in the formulation of meat analogues for the production of sausage analogues.

Formulation code	Ingredients	Percentage (%)
A-1	QF	15
	KF	15
	SPI	70
A-2	QF	25
	KF	15
	SPI	60

Extrusion process

Extrusion tests were carried out in a twin-screw laboratory extruder (Brabender, TwinLabF 20/40, Germany). The screws have a diameter of 20 mm and a length of 795 mm, placed in a barrel 80 cm long. The extruder has four independently temperature-controlled zones set at 40, 60, 80 and 100 °C. The screw configuration from the feed hopper to the inlet of the texturing system was as follows: five SE/30/30 screws, four SE/20/20 screws, two E/30/30 conveyor screws, one KP45/5/20 block mixer, one SE/30/30 conveyor screw, four SE/20/20 screws, four SE/30/30 screws, five SE/20/20 screws, three SE/30 screws and three SE/20 conveyor screws. At the end, there is a texturing head with a cooling system, measuring 25 × 7 mm (Brabender GmbH & Co. KG, 628470, 1935902, Duisburg, Germany), consisting of three nozzles with a total length of 358 mm and an outlet of 126 × 112 mm. The cooling system (Julabo GmbH 600F, 10429787, Germany) was set at 20 °C and the feed rate at 3.7 $kg.h^{-1}$. Both formulations were processed at 57 % humidity and a screw speed of 900 rpm. The initial moisture content of the quinoa, cañihua and SPI flours was determined using a halogen moisture analyser (Mettler Toledo HX204, Spain).

Preparation of sausage analogues

To prepare the sausage analogues, the two meat analogues obtained previously were chopped and mixed with the ingredients listed in Table 2 in a food processor (Thomas 200W TH9005V, Peru) until a homogeneous mixture was obtained, which was stuffed into heat-shrinkable artificial casings (MituAlimentaria, Peru) using a manual stuffer (MZTOGR, China). The sausage analogues were blanched (~80 °C) for 40 minutes and then immersed in water (~5 °C) for storage at room temperature (~18 °C).

Evaluation of physical properties

Texture profile analysis (TPA)

The TPA was performed on the sausage analogues and commercial sausages before and after frying, using an Instron Universal testing machine (model 3365, Norwood, Massachusetts, USA) with a 75 mm diameter round plate and two compression cycles. Cylindrical samples measuring 25 mm in diameter × 10 mm in height were used for the sausage analogues and commercial pork sausages, and 18 × 10 mm samples were used for the commercial chicken sausages. The test speed was 1.00 $mm.s^{-1}$, with two compression cycles, with a preload of 0.10 N until reaching a deformation of 50 % of the sample height; a 500 N load cell was used (Adapted from Huang *et al*., 2025). Five repetitions were performed per sample.

Table 2. Ingredients used in the formulation of sausage analogues.

Ingredients	% Sausage analogue (SA-1)	% Sausage analogue (SA-2)
Meat analogue (A-1)	48	-
Meat analogue (A-2)	-	48
Vegetable shortening (Palma tropical, Peru)	20	20
Ice	17	17
Cassava starch (Mandioca) (Universal, Peru)	10	10
Soy protein isolate (SPI) (Shandong Kawah Oils Co., Ltd, China)	3.8	3.8
Common salt	0.2	0.2
Polyphosphate	0.4	0.4
Ground pepper	0.2	0.2
Ground cumin	0.2	0.2
Monosodium glutamate (Ajinomoto)	0.1	0.1
Carmine coloring	0.1	0.1
TOTAL	**100**	**100**

From this process, the force-deformation curve was obtained and parameters of hardness, cohesiveness, elasticity and chewability were calculated (Isaza Rengifo *et al*., 2010). The data obtained were processed using Bluehill Universal Test Method Development Training software (Instron, Norwood, Massachusetts, USA).

Color determination

Color evaluation was performed by analyzing images of five samples from the surface of the two sausage analogues obtained and the two commercial sausages before and after frying, using the same dimensions as those used in the TPA analysis (Wong *et al*., 2019). Digital images of the samples before and after frying were captured using a color CCD camera (Zeiss, Axiocam 105 color, Jena, Germany), coupled to a stereomicroscope (Carl Zeiss, Stemi 508, Jena, Germany) with a resolution of 2560 × 1920 pixels, with a magnification of 1.25× and a 0.8× objective. A ring light (Prolink, LSH-1200, China) was used for illumination.

The images were captured and stored in jpg format. The red, green and blue (RGB) format was transformed to the hue, saturation and lightness (HSL) model, which more accurately matches human visual perception (Equation 1), using a routine developed in Matlab (Mathworks, Inc., Natick, MA, USA) (Medina *et al*., 2010).

$$= \begin{cases} Arctan\dfrac{\frac{\sqrt{3}}{2}(G-B)}{R-0.5(G+B} \; if\; R-\dfrac{G+B}{2}>0 \\ \pi + Arctan\dfrac{\frac{\sqrt{3}}{2}(G-B)}{R-0.5(G+B)} \; otherwise \end{cases} \tag{1}$$

$$S = 1 - min\left(\frac{R,G,B}{L}\right)$$

$$L = \frac{R+G+B}{3}$$

Cooking yield (CY)

To evaluate CY (Wan Rosli *et al*., 2011), the weight of the sausage analog samples and commercial sausages was recorded before and after the frying process using the same dimensions used in determining TPA (Equation 2). The samples were fried in a frying pan (Crono Récord, Peru) using vegetable oil (Primor, Peru) at ~165 °C for ~30 s on each side of the sample, after which they were removed and excess oil was drained off. Five replicates were performed for each sample.

$$CY = \frac{Final\ weight\ of\ the\ sample\ after\ frying}{Initial\ sample\ weight} \times 100 \qquad (2)$$

Diameter reduction (DR)

Diameter reduction analysis was performed using the methodology employed by Alvis *et al*. (2010). Samples of sausage analogues and commercial sausages (cylinders 25 mm in diameter × 50 mm in height) were fried in a frying pan (Crono Récord, Peru) in a thin, uniform layer of vegetable oil (Primor, Peru) at ~165 °C for ~30 s on each side. After this time, the samples were removed and cooled to room temperature (~18 °C). Subsequently, the final diameters of each sample were measured to calculate DR (Equation 3).

$$DR = \frac{Initial\ diameter - Final\ diameter}{Initial\ diameter} \times 100 \qquad (3)$$

Sensory analysis

The methodology used by Watts *et al*. (1989) was employed for the sensory analysis. The samples evaluated were sausage analogues and commercial fried sausages. Overall appearance, color, smell, taste and overall acceptability were evaluated. A 5-point hedonic scale was used (5 = I like it very much, 4 = I like it, 3 = I neither like nor dislike it, 2 = I dislike it, 1 = I dislike it very much). Considering the rating scale used, the tasting panel was semi-trained, consisting of 25 panelists, both women and men, aged 21 to 24 years. Randomly generated three-digit codes were assigned to each sample for identification. The study was conducted in accordance with ethical research practices and principles (Aguilera-Guzmán *et al*., 2008). Participants received information about the study objectives and signed the respective informed consent form.

Experimental design and statistical analysis

For the analysis of physical and textural properties, a completely randomized design, one-way analysis of variance (ANOVA) together with least significant difference (LSD) tests were used, with a confidence level of 95 % (P-value < 0.05). A completely randomized block design was used for sensory analysis. Results were expressed as mean ± standard deviation. In both cases, Statgraphics Centurion XIX version 19 statistical software was used to identify significant differences in the tests performed.

Results and discussion

Texture profile analysis (TPA)

The results of the TPA analysis for sausages formulated with the two meat analogues (SA-1 and SA-2) and commercial chicken (Chicken-S) and pork (Pork-S) sausages before and after the frying process are presented in Figure 1.

The frying process increased the hardness of the analogues and commercial sausages (Figure 1A) due to the formation of a more compact and cross-linked protein network after prior denaturation by blanching, an effect that is intensified by heat and starch gelatinization (Contardo *et al*., 2016; Montero-Castillo *et al*., 2022; Ramos *et al*., 2021). Fried sausage analogues have an intermediate hardness (between ~52 and ~64 N) compared to commercial sausages (41.05 N for Chicken-S and 83.37 N for Pork-S).

The cohesiveness (Figure 1B) of SA-1 and SA-2 is similar to that of Chicken-S (~0.29) before frying, reflecting adequate structural stability (Torres *et al*., 2015a). However, after frying, the cohesiveness of SA-2 is significantly reduced from 0.32 to 0.21, probably due to the higher proportion of quinoa flour in its formulation (Torres *et al*., 2015b). It is also observed that the cohesiveness of SA-1 increases, as does that of Chicken-S (~0.38).

The elasticity (Figure 1C) and chewiness (Figure 1D) of SA-1 increase after the frying process and resemble those of Chicken-S (~0.74 and ~11 N, respectively). This increase could be attributed to the denaturation of proteins induced by heat treatment, which promotes greater protein cross-linking (Bertram *et al*., 2005). The structural properties of the meat in the sausage formulation play an important role in this behavior, since the values for Pork-S are significantly higher in both cases (~0.8 for elasticity and ~38 N for chewiness) (Herrero *et al*., 2008).

Color determination

Figures 2A and 2B show the values of the components of the HS and HL color models, respectively, for the sausage analogues (SA-1 and SA2) and commercial sausages (Chicken-S and Pork-S), before and after the frying process.

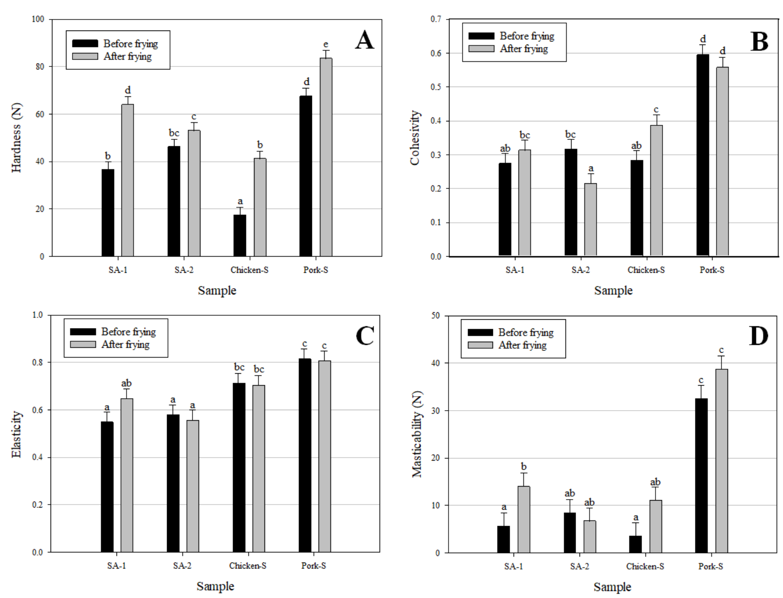

Figure 1. Texture profile (TPA) for sausage analogues (SA-1 and SA-2) and commercial sausages (Chicken-S and Pork-S), before and after the frying process. (A) Hardness, (B) cohesiveness, (C) elasticity and (D) chewiness.

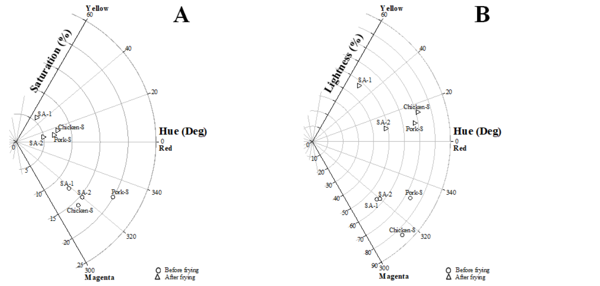

Figure 2. Color parameters, (A) Saturation (%) versus hue (°), (B) Lightness (%) versus hue (°), for SA-1 and SA-2 (sausage analogues), Chicken-S and Pork-S (commercial chicken and pork sausages), before and after the frying process.

Before frying, the sausage analogues (SA-1 and SA-2) and Chicken-S show similar results in terms of hue (~318 °) with saturation between 12.54 to 15.89 %. With regard to lightness, SA-1 and SA-2 had a value of ~60 %, probably due to the influence of vegetable proteins (Schmidt *et al*., 2017; Wu *et al*., 2024), while commercial sausages had higher values (~78 %). This lower brightness could contribute to achieving an appearance similar to artisanal or less processed meat products (Troy and Kerry, 2010).

After frying, all samples decreased in saturation to approximate values of ~5 to 10 % and a change in hue between ~10 - 50 °, which could be due to darkening caused by non-enzymatic browning reactions due to the high temperatures used in frying (Zúñiga and Pedreschi, 2008). The hues with respect to the brightness of SA-2 and commercial sausages (Chicken-S, Pork-S) were ~15 °, which could be attributed to differences in the type of meat used in the sausage formulations (Polizer Rocha *et al*., 2019; Shin *et al*., 2020).

Cooking yield (CY) and diameter reduction (DR)

Figures 3A and 3B show the CY and DR results for the sausage analogues and commercial sausages.

SA-1 had the highest cooking yield (~92.95 %) compared to commercial sausages (~86 %) (Figure 3A), while SA-2 showed values similar to Pork-S (~90 %). According to Hleap and Rodriguez (2015), the incorporation of flours could have influenced the improvement in cooking yield. The RD results (Figure 3B) show that commercial pork sausage (Pork-S) obtained the highest value (~6.4 %), which could be associated with greater fat and water losses during frying (Bertram *et al*., 2005). On the other hand, the DR of SA-1 and SA-2 is similar to that of Chicken-S, with SA-1 standing out slightly. This effect could be due to the fact that the meat analogues were obtained by high-moisture extrusion, which could influence the reduction in shrinkage during frying.

Sensory analysis

The results of the sensory analysis for SA-1, SA-2 and commercial sausages (Chicken-S and Pork-S) are presented in Table 3.

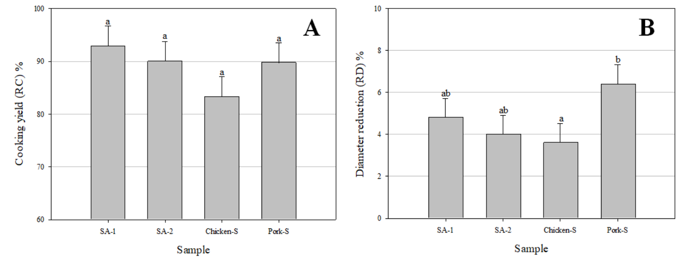

Figure 3. Cooking yield (CY) and diameter reduction (DR) for sausages formulated with the two meat analogues (SA-1 and SA-2) and commercial chicken (Chicken-S) and pork (Pork-S) sausages. (A) CY and (B) DR.

When considering the use of blocks based on the panelists, no significant differences were found between them. Regarding the attributes of the products evaluated, SA-1 and SA-2 had similar profiles in appearance. In color, SA-1 was comparable to commercial sausages. In terms of overall acceptability and smell, SA-1 outperformed commercial sausages (Chicken-S and Pork-S). Overall, both sausage analogues received a positive evaluation, as all parameters evaluated exceeded a value of “3”, which means “neither like nor dislike”. Furthermore, in terms of smell, taste and overall acceptability, the result for SA-1 was “like”, which would support its viability as a sensorially acceptable product.

Conclusions

The physical properties of texture, color, cooking performance and diameter reduction of sausage analogues made with meat analogues, obtained using high-moisture extrusion technology, with the inclusion of Andean crop flours such as quinoa and cañihua in percentages up to 15 % each, are similar to those of commercial sausages made with chicken meat. In terms of sensory analysis, they have a comparable smell and are generally more acceptable than commercial sausages. This means that these products are an alternative for consumers to continue enjoying sausages without considering conventional meats in their formulation.

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Table 3. Results of the sensory analysis of sausage analogues and commercial sausages.

Sample	Appearance	Color	Smell	Flavor	General Acceptability
SA-1	3.44 ± 0.65^{a}	3.72 ± 0.74^{b}	4.08 ± 0.76^{a}	3.96 ± 0.61^{b}	4.04 ± 0.61^{b}
SA-2	3.28 ± 0.94^{a}	3.12 ± 0.88^{a}	3.92 ± 0.57^{a}	3.64 ± 0.76^{a}	3.72 ± 0.61^{a}
Chicken-S	4.00 ± 0.00^{b}	4.00 ± 0.00^{b}	4.00 ± 0.00^{a}	4.00 ± 0.00^{c}	4.00 ± 0.00^{c}
Pork-S	4.00 ± 0.00^{b}	4.00 ± 0.00^{b}	4.00 ± 0.00^{a}	4.00 ± 0.00^{c}	4.00 ± 0.00^{c}

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