Capacidad antioxidante y oxidación lipídica de salchichas de alpaca con quinua roja cocidas por Sous Vide

Antioxidant capacity and lipid oxidation of alpaca sausages with red quinoa cooked sous vide

Capacidade antioxidante e oxidação lipídica de salsichas de alpaca com quinoa vermelha cozida sous vide

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Abstract

Currently, sausage consumption has been linked to health problems due to its high fatty acid and cholesterol content, forcing the use of low-fat meats, natural antioxidants, extenders, and new processing technologies to maintain its nutritional properties and reduce oxidation. The objective of this study was to evaluate the effect of red quinoa as an extender on the antioxidant capacity and lipid oxidation in alpaca sausages cooked sous vide at different temperatures. For the study, alpaca sausages were made by mixing ground alpaca meat, salt, animal fat, and extenders (raw quinoa, quinoa flour, cooked quinoa, and corn starch). The mixtures were cooked sous vide at 60 °C and 80 °C, and stored at 50 °C for 12 days, taking samples on days 1, 7, and 12, to determine the antioxidant capacity (ABTS method), lipid oxidation (TBARS method), pH, color, and texture. The results indicated that the highest values of antioxidant capacity were obtained in alpaca sausages with quinoa flour, causing a lower degree of lipid oxidation, indicated by the low TBARS value, in addition to the greater stability in the values of pH, luminosity (L*), redness (a*) and lower discoloration (b*), which can be attributed to the phenolic antioxidants of red quinoa. In conclusion, the use of red quinoa is an alternative because it can not only be used as an extender in sausage production, but also because it inhibits lipid oxidation and improves the antioxidant activity of the product.

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Resumen

Actualmente, el consumo de salchichas se ha relacionado con problemas de salud, debido a su alto contenido de ácidos grasos y colesterol, obligando al uso de carnes con bajo contenido de grasa, uso de antioxidantes naturales, extensores, además de nuevas tecnologías de procesamiento, para mantener sus propiedades nutricionales y disminuir su oxidación. El objeto de este trabajo fue evaluar el efecto de la quinua roja como extensor sobre la capacidad antioxidante y la oxidación lipídica en salchichas de alpaca cocidas a diferentes temperaturas por Sous Vide. Para el estudio, se elaboraron salchichas de alpaca, mezclando carne molida de alpaca, sal, grasa animal y extensores (quinua cruda, harina de quinua, quinua cocida y almidón de maíz). Las mezclas fueron cocidas en Sous Vide a 60 y 80 °C, y se almacenaron a 50 °C durante 12 días, tomando muestras los días 1, 7 y 12, para la determinación de la capacidad antioxidante (método de ABTS), la oxidación lipídica (método TBARS), pH, color y textura. Los resultados indicaron que los mayores valores de la capacidad antioxidante se obtuvieron en las salchichas de alpaca con harina de quinua, provocando menor grado de oxidación lipídica, indicado por el bajo valor de TBARS, además, por la mayor estabilidad en los valores de pH, luminosidad (L*), enrojecimiento (a*) y menor decoloración (b*), pudiendo atribuirse a los antioxidantes fenólicos de la quinua roja. En conclusión, el uso de quinua roja, es una alternativa porque, no solo puede ser un extensor en la elaboración de salchichas, sino porque, inhibe la oxidación lipídica y mejora la actividad antioxidante del producto.

Palabras clave: salchicha de alpaca, extensor, capacidad antioxidante, oxidación

Resumo

Atualmente, o consumo de salsichas tem sido associado a problemas de saúde devido ao seu alto teor de ácidos graxos e colesterol, necessitando do uso de carnes com baixo teor de gordura, antioxidantes naturais, extensores e novas tecnologias de processamento para manter suas propriedades nutricionais e reduzir a oxidação. O objetivo deste estudo foi avaliar o efeito da quinoa vermelha como extensor na capacidade antioxidante e oxidação lipídica em salsichas de alpaca cozidas em diferentes temperaturas usando sous vide. Para o estudo, salsichas de alpaca foram feitas misturando carne de alpaca moída, sal, gordura animal e extensores (quinoa crua, farinha de quinoa, quinoa cozida e amido de milho). As misturas foram cozidas em sous vide a 60 e 80 °C e armazenadas a 50 °C por 12 dias, coletando amostras nos dias 1, 7 e 12, para determinar a capacidade antioxidante (método ABTS), oxidação lipídica (método TBARS), pH, cor e textura. Os resultados indicaram que os maiores valores de capacidade antioxidante foram obtidos em linguiças de alpaca com farinha de quinoa, causando menor grau de oxidação lipídica, indicado pelo baixo valor de TBARS, além de maior estabilidade nos valores de pH, luminosidade (L*), vermelhidão (a*) e menor descoloração (b*), o que pode ser atribuído aos antioxidantes fenólicos da quinoa vermelha. Em conclusão, o uso da quinoa vermelha é uma alternativa, pois, não só pode ser um extensor na produção de linguiças, mas também porque inibe a oxidação lipídica e melhora a atividade antioxidante do produto.

Palavras-chave: salsicha de alpaca, extensor, capacidade antioxidante, oxidação.

Introduction

There is a growing trend toward shifting from a meat-centered diet to a plant-based diet, improving the impacts on the environment and public health (Lang, 2020). In response to this, new strategies are being introduced, one of which is related to the use of functional ingredients, such as meat extenders (Rocchetti *et al*., 2023), which are non-meat substances with high protein content that can modify the water-holding capacity, texture, palatability, and appearance (Pintado and Delgado-Pando, 2020). The use of extender ingredients improves the nutritional profile of meat products, enhancing protein quality and also changing the protein or creating new possibilities for increasing shelf life and diversity of functional properties (Owusu-Ansah *et al*., 2022).

Sausages are widely consumed meat products, valued for their protein and fat content (Huang *et al*., 2025). These are made with ground meat, along with various ingredients, including fat, salt, spices, stabilizers, antioxidants, flavorings, and extenders, stuffed into a casing (Nyaguthii *et al.*, 2023). However, there is concern about excessive sodium intake (Adeyemi *et al*., 2025), chemical preservatives (Zeraat Pisheh *et al*., 2025), and fat and cholesterol levels, which have led to several studies seeking to ensure that animal fat meets the characteristics required for health (Monteiro *et al*., 2017). According to Cruz-Tirado *et al*. (2024), alpaca meat could be an alternative, due to its protein content (22 – 24 %) which is comparable to the meat of other animals such as lamb (19–20 %) and beef (21.7 – 21.9 %) additionally, it has low levels of intramuscular fat (<1 %) and lipid oxidation (<2.44 mg MDA.kg-1 of meat) compared to other species of red meat (Smith *et al*., 2019).

On the other hand, cereals have been used as extenders to increase water and fat holding in sausages, improving their performance (Muchekeza *et al*., 2021). An alternative is quinoa, not only because it is rich in protein, but also because it is an important source of phenolic acids and flavonoids that contribute to its functional properties, such as antioxidant, anti-inflammatory, antimicrobial, and anti-cancer (Ma *et al*., 2023). Consequently, the objective of this study was to evaluate the effect of red quinoa as an extender (raw quinoa, quinoa flour, cooked quinoa) compared to corn starch on the antioxidant capacity and lipid oxidation of alpaca sausages cooked sous vide at 60 and 80 °C.

Materials and methods

Quinoa and alpaca

The red quinoa grains were acquired from the National Institute of Agrarian Innovation-Puno. The alpaca meat was purchased from the supply center of the city of Puno.

Processing of red quinoa

The red quinoa grains were mechanically processed. First, they were washed ten times with distilled water to remove the shell and dried at 55 °C for 8 hours, obtaining raw quinoa (RQ). Then, the grinding and cooking processes were carried out. The dry quinoa was ground (FRITSCH model PULVERISSETE 14, Germany) into flour, then sifted using a 200 μm sieve and stored at 4 °C until use, which was called quinoa flour (QF). For pressure cooking, 100 g of dry quinoa with 30 mL of distilled water was placed in a beaker, stirred, and left to rest for 2 hours. Then, cooking was carried out for 20 min in an autoclave (GREETMED model LS-B50L-II, China) at 0.1 MPa and 120 °C, passed through a sieve, and stored at 4°C until use, which was called cooked quinoa (CQ).

Production of alpaca sausages with red quinoa as an extender

For the production of alpaca sausages, the procedure proposed by Muchekeza *et al*. (2021) was followed; the alpaca meat was cut into pieces (50 mm × 50 mm × 50 mm) and taken to a meat grinder (IMACO model FP7581, China), with the addition of 2 % salt, 10 % animal pork fat, 5 % cold water, and 3 % extender (raw quinoa, quinoa flour, cooked quinoa, and corn starch). Portions of 30 to 38 g of this mixture were stuffed into casings to produce sausages; they were packed in poly bags using a vacuum packer (HENKELMAN Jumbo 42 I model, Holland) programmed for 20 seconds. The mixture was stuffed into casings of 30 to 38 g of each sausage, packed in plastic bags, then cooked sous vide (OLISO model IH95A, China) at 60 °C and 80 °C for 30 minutes and cooled to 15 °C. The processing was repeated three times with each formulation. For the study, the samples were stored in a convection oven at 50 °C for 12 days, and samples were taken at 1, 7, and 12 days; each of them was refrigerated at 4 °C until analysis.

Cooking loss

The cooking weight losses of the alpaca sausages were determined according to what was indicated by Choe *et al*. (2013), with some modifications. Alpaca sausage samples were weighed before and after cooking to calculate cooking losses as follows:

$$\text{Cooking loss (\%)} = \frac{\text{Weight before cooking-Weight after cooking}}{\text{Weight before cooking}} \times 100$$

Determination of antioxidant capacity

To determine the antioxidant capacity, the $ABTS^{+2}$ method proposed by Re *et al.* (1999) was used. To obtain the methanolic extract, 1 g of the sample and 25 mL of 80 % v/v methanol were stirred for 5 min, then the mixture was left to rest for 24 hours at 4 °C, centrifuged at 2000 rpm for 10 min, and the resulting supernatant was used for the quantification of antioxidant capacity. The results were expressed as µmol equivalent of Trolox.g^{-1}.

Determination of the content of thiobarbituric acid reactive substances (TBARS)

Oxidation was evaluated by determining the content of thiobarbituric acid reactive substances (TBARS) as proposed by Rosmini *et al*. (1996) with some modifications. Five grams (5 g) of sausage samples were mixed with 25 mL of 15 % trichloroacetic acid, then the samples were homogenized for 1 min in a blender and left for 15 min at -10 °C in a freezer to improve precipitation. Subsequently, the samples were filtered, and 5 mL was taken to mix with 5 mL of thiobarbituric acid 0.02 M. Subsequently, the samples were mixed at 1200 rpm for 20 s and incubated for 35 min in a boiling bath. After cooling, the samples were measured at 532 nm in a spectrophotometer (GENESYS 20 model 4001/4, USA). The TBARS content was expressed in mg of malondialdehyde (MDA) per kg of sample.

pH, color, and texture

The pH values were determined using a pH meter (MILWAUKEE model MI150, Romania) at room temperature, according to the method proposed by Wang *et al*. (2018).

The internal color of all cooked samples was determined using a colorimeter (SADT model SC20, China) calibrated with a white background. The values L* (luminosity), a* (redness), and b* (discoloration) were recorded, following the procedure proposed by Kasaiyan *et al*. (2023).

The texture of alpaca sausages was determined using a texture analyzer (Brookfield CT3-4500, USA), following the procedure proposed by Li *et al*. (2023) with some modifications.

Experimental design and statistical analysis

A completely randomized design was performed, with eight treatments (table 1) and three replications per treatment, for a total of 24 experimental units.

Table 1. Treatments with red quinoa and sous vide cooking temperature in alpaca sausages.

Treatments	Extender	Sous vide cooking temperature
T1	Raw quinoa	60 °C
T2	Raw quinoa	80 °C
T3	Quinoa flour	60 °C
T4	Quinoa flour	80 °C
T5	Cooked quinoa	60 °C
T6	Cooked quinoa	80 °C
T7	Corn starch	60 °C
T8	Corn starch	80 °C

Results were expressed as mean and standard deviation. ANOVA and Tukey's test were applied to the response variables ($p < 0.05$). Statistical analyses of the data were performed using Statgraphics Plus for Windows 4.0 (Statpoint Technologies, Inc., VA, USA).

Results and discussion

Cooking weight loss of alpaca sausage with red quinoa as an extender

Cooking weight loss showed a non-significant change between treatments ($p > 0.05$) with the lowest values in treatments with red quinoa cooked at 60 °C (T5), as shown in figure 1.

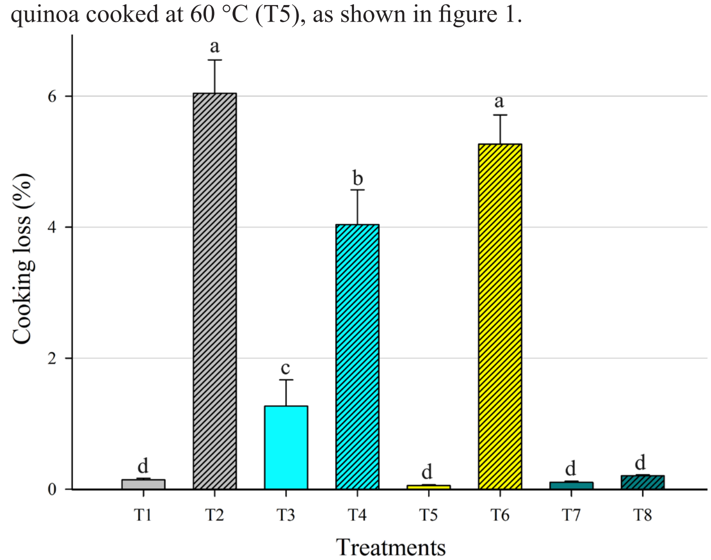

Figure 1. Weight loss of alpaca sausage by cooking.

Alpaca sausages with red quinoa cooked sous vide at 60 °C showed less weight loss by cooking ($p > 0.05$), with a maximum of 1.23 % with the addition of quinoa flour. This phenomenon was also observed in the cooking of sausages made with cooked quinoa, which was lower compared to corn starch. In this regard, Muchekeza *et al*. (2021), indicated that the decrease or increase in weight loss by cooking is due to the loss of moisture, related to the action of the starch or type of protein in quinoa flour. Likewise Manzoor *et al*. (2022) indicate that weight loss due to cooking causes a reduction of nutrients that are soluble in water, as well as color-forming pigments.

Change in antioxidant capacity in alpaca sausages during storage

The ability to inhibit lipid peroxidation was one of the indicators of the antioxidant activity of red quinoa in its different preparations.

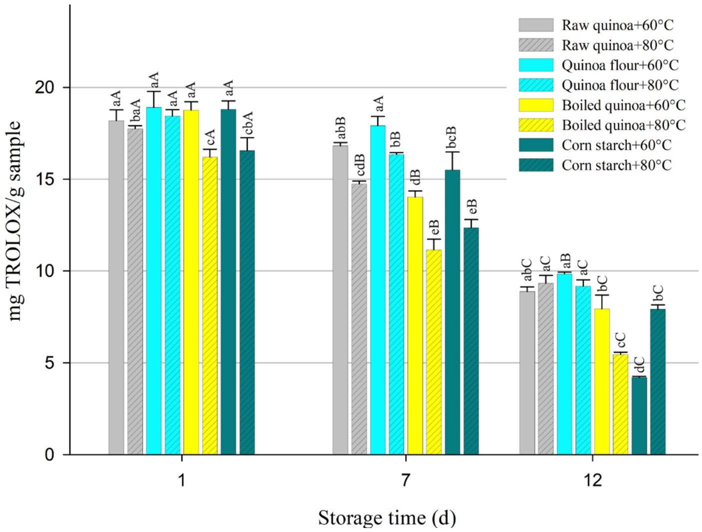

Figure 2. Change of antioxidant capacity in alpaca sausages. The results are expressed as mean and standard deviation. Values with different lowercase letters (a-e) at the same time; values with different capital letters (A-C) in the same treatment.

Alpaca sausages made with the addition of raw quinoa and quinoa flour as an extender had high antioxidant capacity values compared to sausages made with corn starch, possibly due to the antioxidant content provided by this raw material. Different studies indicate that colored grains have a greater potential as ingredients in food systems, due to the high protein content and their phenolic compounds, such as phenolic acids, flavonoids, kaempferol, and quercetin (Fernández-López *et al*., 2020). In addition, quinoa's high antioxidant activity reflects its ability to donate hydrogen atoms and electrons to interrupt radical reactions and chelate transition metal ions (Sharma *et al*., 2022), being able to inhibit oxidation in alpaca sausages.

Change in TBARS of alpaca sausages during storage

During storage, the TBARS values of the treatments changed significantly and were different among the treatments ($p < 0.05$), as shown in figure 3. Concerning TBARS values, Naqvi *et al*. (2022), point out that a high TBARS value is associated with deterioration, as well as indicates that the sous vide cooking technique helps to reduce the rate of oxidation.

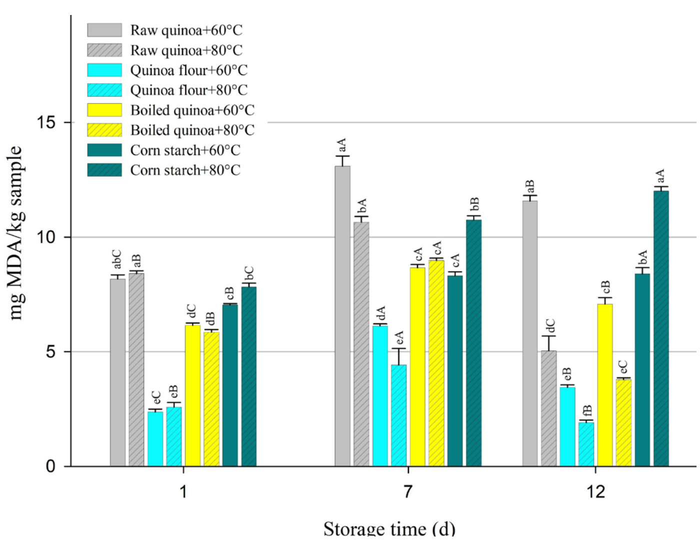

Figure 3. Change in TBARS of alpaca sausages. The results are expressed as mean and standard deviation. Values with different lowercase letters (a-f) at the same time; values with different capital letters (A-C) in the same treatment.

The results obtained show that alpaca sausages with quinoa flour cooked sous vide at 60 °C and 80 °C presented the lowest TBARS values compared to the other treatments. This could be due to the inhibitory effect of the antioxidants of quinoa flour and the sous vide cooking on oxidation during storage of alpaca sausages. In this regard, Deng *et al*. (2024) mention that gallic acid could prevent lipid and protein oxidation by acting as a scavenger and inhibitor of ROS.

Change in pH, color, and texture of alpaca sausages during storage

The pH value during storage decreased in almost all treatments ($p< 0.05$). Likewise, depending on how the quinoa was prepared, the pH of the alpaca sausage changed, as shown in table 2.

Table 2. pH value of alpaca sausages with red quinoa cooked sous vide.

Treatments	Time		
	Day 1	Day 7	Day 12
pH			
T1	5.2±0.1^{abA}	4.8±0.1^{cdA}	4.7±0.3^{abcA}
T2	5.4±0.0^{aA}	5.2±0.1^{aA}	5.0±0.1^{aA}
T3	5.2±0.1^{abA}	4.5±0.1^{bdB}	4.0±0.1^{dC}
T4	5.2±0.0^{abA}	5.0±0.3^{abcA}	4.7±0.6^{abcA}
T5	5.1±0.1^{bA}	4.7±0.1^{dB}	4.4±0.1^{bcB}
T6	5.2±0.0^{abA}	5.2±0.0^{abA}	4.8±0.1^{abB}
T7	5.1±0.1^{bA}	4.8±0.1^{bcdB}	4.3±0.0^{cdC}
T8	5.3±0.1^{abA}	5.2±0.1^{aA}	4.4±0.0^{bcB}

The results are expressed as mean and standard deviation. Lowercase letters indicate significant differences ($p < 0.05$) between rows (treatments). Capital letters indicate significant differences ($p < 0.05$) between columns (storage time).

The lowest pH value was observed at T3 (quinoa flour + 60 °C) compared to the other treatments. These low pH values could be attributed to microbial growth retardation Manzoor *et al*. (2022). On the other hand, Luan *et al*. (2021) mention that lowering pH can decrease the coagulation and water-holding capacity of meat proteins. Additionally, Çelebi and Erge, (2024) claim that pH changes are caused by the electrostatic interaction between proteins and starches.

The color change in alpaca sausages during storage (table 3) was observed in the different decreases in the L^*, a^*, and b^* values ($P < 0.05$).

According to the results, T3 (quinoa flour + 60 °C) presented the lowest L^* value, which is attributed to the oxidation of myoglobin induced by pro-oxidants to form metmyoglobin (Adeyemi *et al*., 2025), causing a decrease in the a^* and b^* values of sausages as well as the soft texture of cooked sausages, causes lower brightness, with a higher L^* value compared to those formed in gels. In addition, phenolic compounds can act as scavengers and ROS inhibitors to inhibit myoglobin oxidation and exert a protective effect on color (Deng *et al*., 2024). In this regard, Deepitha *et al*. (2021) mention that the interaction with phenolic compounds inhibits the process of initiation of myoglobin to its hypervalent state of ferryl myoglobin.

Table 3. Color of alpaca sausages with red quinoa cooked sous vide.

Treatments	Time		
	Day 1	Day 7	Day 12
L*			
T1	63.8±3.8cA	63.6±2.5cdA	63.1±2.1bA
T2	64.0±2.7cA	63.3±2.6dAB	60.7±0.4cdC
T3	60.2±3.1dA	59.0±0.9eA	59.0±2.7dA
T4	64.6±1.3bcA	62.9±1.0dB	62.0±1.0bcB
T5	66.0±1.4bcA	65.6±1.8bcA	63.4±0.9bB
T6	72.2±1.1aA	70.8±0.4aA	66.7±1.7aB
T7	66.9±1.5 bA	66.8±2.3bA	66.3±1.1aA
T8	70.7±0.5 aA	69.5±0.8 aB	67.2±0.5 aC
a*			
T1	15.0±1.3aA	11.9±0.7aB	11.5±0.9aB
T2	9.2±1.1cA	8.6±0.3cdB	7.2±0.5cdB
T3	11.8±0.8bA	11.5±0.3abA	8.1±0.7bcB
T4	8.9±0.4cA	8.0±0.4dB	6.2±0.4dC
T5	11.8±1.0bA	9.3±0.2cB	8.7±1.8bB
T6	8.5±1.8cA	8.1±1.6dA	7.1±1.3cdA
T7	11.9±0.3bA	10.8±0.4bB	7.0±0.6cdC
T8	8.3±0.2cA	8.0±0.4dA	7.0±1.0cdB
b*			
T1	7.5±0.8abcA	6.6±0.4cdB	6.2±0.3bcB
T2	8.4±0.6aA	8.2±0.4aA	7.7±0.9aA
T3	6.6±0.6bcA	6.2±0.4cdA	6.0±1.3bcA
T4	6.2±1.4cA	6.1±0.7dA	6.0±0.6bcA
T5	6.3±0.5bcA	6.3±0.6cdA	5.3±0.8cA
T6	7.6±1.9abA	7.3±0.7bA	7.6±0.9aA
T7	6.9±1.2bcA	6.4±0.4cdA	5.7±0.7bcA
T8	7.0±0.5bcA	6.9±0.5bcA	6.5±0.8bA

The results are expressed as mean and standard deviation. Lowercase letters indicate significant differences ($p < 0.05$) between rows. Capital letters indicate significant differences ($p < 0.05$) between columns.

The *a** value of red quinoa treatments was lower than that of cornstarch, indicating that red quinoa helps preserve redness in alpaca sausages. Kasaiyan *et al*. (2023) mention that the parameter *a** could be related to moisture loss and higher protein concentration in cooked sausages. In addition Zhang *et al*. (2022) mention that meat, due to its moisture content, allows better diffusion of color in the tissue, resulting in darker meat. Therefore, the use of red quinoa flour is an alternative as a binder in sausages, improving the concentration of proteins and the diffusion of color, together with the contribution of antioxidants for the inhibition of oxidation.

As for the *b** value, the red quinoa treatments were lower and the same compared to the corn starch treatments, indicating that red quinoa reduces discoloration, since an increase in the hue angle means more discoloration (Manzoor *et al*., 2022).

The change in texture values indicated by hardness and work were significantly different between treatments, and some treatments decreased significantly during storage ($p < 0.05$), as shown in table 4.

Table 4. Alpaca sausage texture with red quinoa cooked sous vide.

Treatments	Time (days)		
	Day 1	Day 7	Day 12
Hardness g			
T1	3544.2±64.0dA	2833.0±88.9eB	1955.8±85.5eC
T2	2788.0±51.9eAB	2632.0±71.4fB	2827.2±62.7cA
T3	4361.0±68.1bA	3191.7±31.8dB	2859.5±68.2cC
T4	3781.0±65.8cB	4966.8±88.9aA	3398.7±62.1bC
T5	4226.3±92.0bA	2286.2±62.9gB	2141.2±95.4eB
T6	3815.5±58,1cA	3289.2±6.4dB	1231.2±45.2fC
T7	3799.2±52.5cA	3684.7±72.2cB	2509.5±32.3dB
T8	4768.2±83.6aA	4640.3±29.4bA	4346.0±103.1aB
Work mJ			
T1	159.7±30.2bA	100.0±6.4cB	101.8±11.1bcB
T2	128.7±24.0 bA	114.3±7.3bcA	149.7±5.6bA
T3	160.6±25.0 bA	164.6±63.2abcA	125.1±3.5bcA
T4	140.3±31.1bB	224.3±0.3abA	141.6±0.8bB
T5	169.6±64.6bA	99.4±17.7cA	107.5±9.3bcA
T6	197.1±16.3abA	146.3±6.3cB	65.7±5.6cAC
T7	155.43±8.5 bA	158.1±6.9bcA	90.5±68.1bcA
T8	261.2±15.9aA	228.5±3.1aA	234.4±26.9aA

The results are expressed as mean and standard deviation. Lowercase letters indicate significant differences ($p < 0.05$) between rows. Capital letters indicate significant differences ($p < 0.05$) between columns.

During storage, the hardness value in the treatment with quinoa cooked sous vide at 60 °C is lower compared to the treatment with corn starch ($p < 0.05$). In this regard, Zhang *et al*. (2022) indicate that the denaturation of proteins causes hardness in meat, while cooked quinoa, due to the stability of the protein, reduces hardness in sausages.

Conclusions

Red quinoa and sous vide cooking at the evaluated temperatures have an effect on the oxidative activity and lipid oxidation of alpaca sausages. The use of quinoa flour as an extender subjected to cooking at 60 °C showed the highest value in antioxidant capacity and the lowest value in TBARS, presenting a stable pH value, maintaining brightness, preserving redness, less discoloration, and considerable hardness during storage, evidencing the effect of red quinoa antioxidants on the oxidation of alpaca sausage.

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