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Understanding lipid oxidation in dried meat and cured dried meat: Insights from peroxide index analysis

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Abstract

The lipid oxidation process is one of the main food spoilage reactions, resulting in the appearance of unpleasant flavors and odors, known as rancidity. This study aimed to evaluate the lipid oxidation activity through the peroxide index, together with some chemical and biochemical constituents, of meat products with a high sodium content that underwent salting process and were sold to consumers. Samples of dried meat/charqui (CA: n = 22 and CB: n = 22) and jerked beef (JBA: n = 27 and JBB: n = 27) were analyzed. The peroxide index, rancidity test, formaldehyde test, sodium chloride, sodium, nitrite, proximate composition, and calories were analyzed. The main results demonstrated a high peroxide index and nitrite concentrations in jerked beef samples (JBA and JBB). The high concentrations of moisture and nitrite probably increased lipid oxidation in jerked beef samples, and lipid oxidation activity was inhibited by high concentrations of sodium chloride in dried meat samples.

Keywords: oxidation activity; dried meat; peroxide index; jerked beef.

Practical Application: Evaluation of lipid oxidation in high sodium meat products using peroxide index.

1 INTRODUCTION

Lipid oxidation, an intricate biochemical process, emerges as a fundamental concern in the food industry, given its direct influence on product sensory quality and safety. This reaction, catalyzed by specific agents, initiates a cascade of events culminating in the formation of oxygenated compounds such as alcohols, aldehydes, ketones, and peroxides, imparting undesirable flavor and aroma notes to foods. This phenomenon, besides being responsible for the development of rancid flavors, leads to the nutritional degradation of foods and, in some cases, the generation of toxic products. Lipid oxidation, at its core, involves the transfer of electrons between molecules, wherein an oxidizing agent captures electrons while a reducing agent donates them (Baron et al., 2020; Ordóñes, 2005; Vannucchi et al., 1998).

The unsaturation present in fatty acids constitutes the primary site of reaction with oxygen. Unsaturated fatty acids, in their free form, tend to oxidize more readily. The concept of free radicals is central in this context, referring to atoms or molecules with unpaired electrons in outer orbitals, rendering them highly reactive (Baron et al., 2020; Ordóñes, 2005; Vannucchi et al., 1998).

Evaluating lipid oxidation in foods often relies on determining the peroxide value, which reflects the difference between the formation and decomposition of these compounds, expressed in millimoles of active oxygen per kilogram of fat (Instituto Adolfo Lutz, 2008). It is widely accepted that early determination of this value is crucial, as its variation over time follows a Gaussian pattern, such that low initial levels may mask subsequent deterioration (Berset & Cuvelier, 1996; Silva et al., 1999).

In beef, lipid oxidation can be triggered by endogenous factors such as the presence of lipases, metallic ions, and heme groups, as well as by processing procedures that compromise the integrity of muscle tissue membrane systems, exposing lipid fractions vulnerable to oxidation (de Lima Júnior et al., 2013; Min et al., 2008; Ponnampalam et al., 2012). The stability and preservation of beef are attributed to the compartmentalized or discontinuous form in which some of its constituents are distributed within the tissue matrix. Processing methods that disrupt muscle membrane systems, such as grinding, cooking, salting, boning, smoking, and slow freezing, expose oxidizable lipid fractions to reactive groups, favoring the onset of rancidity (de Lima Júnior et al., 2013; Sampels et al., 2004).

Charqui (dried meat) and jerked beef (cured dried meat), examples of meat products subjected to salting processes, are emblematic of this dynamic. Both, derived from beef, undergo the action of sodium chloride and other additives, as well as desiccation processes, resulting in final products with unique characteristics (Brasil, 2000). Therefore, charqui is considered salted and desiccated beef (dried meat). Jerked beef, salted and

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cured beef or cured dried meat, is regarded as an industrialized meat product obtained from beef, added with sodium chloride and curing salts (sodium chloride, nitrite, and nitrate), and subjected to a maturation and desiccation process (Brasil, 2000).

In this context, the present study aimed to evaluate the lipid oxidation activity, through the peroxide index, and the chemical and biochemical composition of meat products with high sodium content, subjected to the salting process and marketed for human consumption.

2 MATERIAL AND METHODS

2.1 Samples

The samples were sent to the Food Inspection Laboratory of the Department of Animal Production and Preventive Veterinary Medicine, Universidade Estadual Paulista "Júlio de Mesquita Filho", School of Veterinary Medicine and Animal Science, in Botucatu, in the state of São Paulo, Brazil. Two brands of charqui, CA (n = 22) and CB (n = 22), and two brands of jerked beef, JBA (n = 27) and JBB (n = 27), marketed in São Paulo were analyzed. The samples were ground, homogenized, and stored in sterile plastic bags under refrigeration (± 4°C) before the physicochemical assays were performed. Laboratory assays were conducted in triplicate.

2.2 Determination of peroxide value

Five grams of the sample fat were weighed into a 250 mL or 125 mL Erlenmeyer flask. Thirty milliliters of an acetic acid-chloroform solution in a 3:2 ratio were added. The flasks were shaken until the sample fat dissolved. Then, 0.5 mL of saturated potassium iodide solution was added, and the mixture was left to stand in the dark for exactly one minute. Thirty milliliters of pure water were added. Titration was performed with 0.1 N sodium thiosulfate solution (or 0.01 N), with constant agitation, until the yellow color almost disappeared. Next, 0.5 mL of 1% starch solution was added, and titration was continued until the blue color disappeared completely. Additionally, a flask with the reagents and without the sample was titrated and considered a blank. The volume (mL) of 0.1 N sodium thiosulfate solution used was applied to the following peroxide value formula (Equation 1):

$$\text{mEq/kg: } [(A - B) \times N \times f \times 1{,}000] / M1 \quad (1)$$

Where:

A: 0.1 N (or 0.01 N) sodium thiosulfate solution used in the titration of the sample (mL);

B: 0.1 N (or 0.01 N) sodium thiosulfate solution used in the titration of the blank (mL);

N: normality of the sodium thiosulfate solution (0.1 or 0.01);

M1: grams of the sample; and

f: correction factor of the sodium thiosulfate solution.

(Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.3 Qualitative assay for formaldehyde

Five grams of the sample were weighed into a Kjeldahl tube, and 20 mL of 20% phosphoric acid solution was added. The Kjeldahl distillation apparatus was heated to boiling, and approximately 40 mL were distilled into a 250 mL Erlenmeyer flask. Five milliliters of the distillate were transferred to a test tube. Then, 1 mL of 1% phloroglucinol solution and 2 mL of 10% sodium hydroxide solution were added. A salmon coloration appeared in the presence of formaldehyde (Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.4 Qualitative assay for rancidity

Two grams of fat from the sample were transferred to a 25 mL stoppered flask. Carefully, 2 mL of concentrated hydrochloric acid solution (approximately 36%) was added. The flask was stoppered and shaken for 30 seconds. Then, 2 mL of 0.1% phloroglucinol solution in ethyl ether was added. The mixture was shaken again for 30 seconds and left to stand for 10 seconds to allow for layer separation. In the presence of rancidity, the lower layer exhibited a pink or red coloration (Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.5 Moisture determination

Five grams of the sample were weighed into a porcelain crucible previously heated in an oven at 105°C for two hours, cooled in a desiccator with silica gel to room temperature, and reweighed. The crucible with the sample was then heated in an oven at 105°C for six hours, cooled in a desiccator with silica gel to room temperature, and reweighed. The calculation was performed using the following formula (Equation 2):

$$\text{Moisture (\%)} = (100 \times N) / M \quad (2)$$

Where:

N: grams of moisture (mass loss in grams);

M: grams of the sample.

(Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.6 Fixed mineral residue determination

Two grams of the sample were weighed into a porcelain crucible previously heated in a muffle furnace at 550°C for two hours, cooled in a desiccator with silica gel to room temperature, and reweighed. The sample was carbonized on a heating plate at a low temperature. The carbonized sample was incinerated in a muffle furnace at 550°C for six hours until it turned white or slightly grayish. It was then cooled in a desiccator with silica gel to room temperature and reweighed. The fixed mineral residue (FMR) calculation was performed using the following formula (Equation 3):

$$\text{FMR (\%)} = (100 \times N) / M \quad (3)$$

Where:

N: grams of ashes;

M: grams of the sample

(Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.7 Sodium chloride determination

Two or three drops of 1 + 9 nitric acid solution were added to the mineral residue obtained in the FMR determination. Then, 10 mL of hot pure water was added. The mixture was homogenized with a glass rod and transferred to a 500 mL Erlenmeyer flask. The porcelain crucible was rinsed with four aliquots of 20 mL of hot pure water, and the rinses were transferred to the flask. Next, 0.5 g of calcium carbonate was added to the flask and homogenized. After cooling, 1 mL of 10% potassium chromate solution was added. Titration was performed with 0.1 M silver nitrate solution, and the volume used (mL) was applied to the following formula (Equation 4):

$$NaCl\ (g/100\ g) = (V \times f \times 0.585) / M \quad (4)$$

Where:

V: 0.1 M silver nitrate solution used in titration (mL);

f: factor of 0.1 M silver nitrate solution;

M: grams of the sample.

(Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.8 Sodium determination

The value obtained in the sodium chloride determination by the Mohr method described above was used. The sodium chloride value was applied to the following formula (Equation 5):

$$Sodium\ (g/100\ g) = (NaCl \times 23) / 58.5 \quad (5)$$

Where:

NaCl: g/100 g obtained by the Mohr method;

23: Na atomic mass (g/mol);

58.5: NaCl molecular mass (g/mol).

(Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.9 Determination of nitrite

Ten grams of crushed and homogenized samples were weighed in a 200 mL beaker. Five milliliters of 5% sodium tetraborate solution were added. Approximately 50 mL of pure water was added, and the mixture was kept in a water bath at 80°C for 20 minutes, with frequent stirring using a glass rod. The same procedure was done with a reagent blank without adding the sample. Using a glass rod and a funnel, the contents were quantitatively transferred to a 200 mL volumetric flask, rinsing the beaker with pure water. Five milliliters of 15% potassium ferrocyanide solution and 5 mL of 30% zinc acetate solution were added. The mixture was stirred by rotation after the addition of each reagent, and the volume was made up of pure water. It was left to stand for 15 minutes, shaking vigorously several times during this period. It was filtered through qualitative filter paper into a clean, dry flask. Ten milliliters of the filtrate were transferred to a 50 mL volumetric flask. Five milliliters of 0.5% sulfanilamide solution were added. It was left to react for 5 minutes, and then 3 mL of 0.5% alpha-naphthyl ethylenediamine chloride solution was added. The volume was made up of pure water and homogenized. It was left to stand for 15 minutes, and the absorbance was read at 540 nm. The absorbance value was applied to the following formula obtained from the standard curve (Equation 6):

$$NaNO2\ (mg/kg) = [(A - 0.0134) \times 1{,}000] / (M \times 0.6993) \quad (6)$$

Where:

A: absorbance;

M: grams of the sample.

(Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.10 Protein determination (Kjeldahl method)

A quantity of 0.5 grams of the homogenized sample was weighed onto filter paper before being transferred to a Kjeldahl tube. Ten milliliters of sulfuric acid (1.820–1.825 g/mL or 1.84 g/mL) and approximately one gram of the catalytic mixture was added. The tube was placed in the TE-007 Tecnal® digestion block at 400°C for approximately four hours in the fume hood until the solution turned blue-green and was free of undigested material (black spots). After cooling, the tube was transferred to the TE-0364 Tecnal® nitrogen distillation apparatus. The tapered end of the condenser was immersed in 10 mL of 0.05 M sulfuric acid contained in a 250 mL Erlenmeyer flask with four drops of 0.2% methyl red indicator. Sodium hydroxide solution (40%) was added to the Kjeldahl tube containing the digested sample using a funnel with a stopcock until a slight excess of base was ensured. The mixture was heated to boiling and distilled until approximately 150 mL (± 5 minutes) of distillate was obtained. The excess sulfuric acid (0.05 M) was titrated with 0.1 M sodium hydroxide solution. Calculation (Equation 7):

$$Protein\ (\%) = (V \times 0.14 \times f) / M \quad (7)$$

Where:

V: difference between the volume (mL) of 0.05 M sulfuric acid solution used and the volume (mL) of 0.1 M sodium hydroxide solution used in titration;

M: grams of the sample;

f: 6.25.

(AOAC, 1995; Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.11 Lipid determination (Soxhlet method)

Two to five grams of the sample were weighed into a cellulose Soxhlet cartridge. The sample was dried in an oven at 105°C for one hour. A small portion of hydrophilic cotton was placed in the cartridge. The cartridge was transferred to the Soxhlet extractor TE-044 Tecnal®. The previously reset reboiler flask at 105°C was attached to the extractor. Sufficient ethyl ether (approximately 80 mL) was added. The equipment parts were properly adapted and heated for continuous extraction for six to eight hours. The reboiler flask was removed after all the ethyl ether was recovered. The flask with the extracted residue was transferred to an oven at 105°C for one hour, and then cooled in a desiccator to room temperature. It was weighed and the heating and cooling operations were repeated for 30 minutes in the oven until a constant weight was achieved (up to two hours maximum). Calculation (Equation 8):

$$\text{Lipids (\%)} = (N \times 100) / M \quad (8)$$

Where:

N: grams of lipids;

M: grams of the sample.

(AOAC, 1995; Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.12 Carbohydrate determination

The values obtained in the protein (%), lipid (%), moisture (%), and FMR (%) determinations were used. These values were applied to the following formula (Equation 9):

$$\text{Carbohydrates (\%)} = [100 - (\text{protein} + \text{lipid} + \text{moisture} + \text{FMR})] \quad (9)$$

(Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.13 Caloric content

The caloric values per gram for protein (4 kcal), lipid (9 kcal), and carbohydrate (4 kcal) were utilized. The obtained values were applied to the following formula (Equation 10):

$$\text{Calorie (kcal/100 g)} = [(\text{protein} \times 4) + (\text{lipid} \times 9) + (\text{carbohydrate} \times 4)] \quad (10)$$

(Brasil, 1981, 2005, 2022; Instituto Adolfo Lutz, 2008).

2.14 Statistical analysis

The outcomes of the quantitative assays, executed in triplicate, underwent statistical scrutiny utilizing analysis of variance (ANOVA) within a fully randomized design, bolstered by Tukey's test for mean contrast. Significance in the statistical analyses was set at a 5% threshold. Conversely, the findings from qualitative assays (formaldehyde and rancidity) were assessed by absolute frequencies, relative frequencies, and percentages (Montgomery, 2020).

3 RESULTS

The brands CA (0.35 mEq/kg ± 0.05 mEq/kg) and CB (0.35 mEq/kg ± 0.05 mEq/kg) presented mean values of peroxide index significantly lower ($p < 0.01$) than the brands JBA (1.01 mEq/kg ± 0.12 mEq/kg) and JBB (1.00 mEq/kg ± 0.11 mEq/kg). There were no significant differences observed between the charqui brands (CA and CB) and jerked beef brands (JBA and JBB). The collected data showed a stable and homogeneous coefficient of variation (CV) (13.47%) (Table 1). In all qualitatively analyzed samples, no formaldehyde or rancidity was detected (Table 2). The statistical results demonstrated that the peroxide index was higher in the jerked beef samples.

Table 3 shows the results of the additives sodium chloride (NaCl), sodium ions (Na+), and nitrite (NO2-) present in the charqui and jerked beef samples. Regarding the NaCl content, the brands CA (14.61 g/100 g ± 1.54 g/100 g), CB

Table 1. Mean ± standard deviation of peroxide value (mEq/kg) of charqui (brands CA and CB) and jerked beef (brands JBA and JBB) samples.

Sample	n	Mean ± standard deviation
CA	22	0.35 ± 0.05 a[1]
CB	22	0.35 ± 0.05 a
JBA	27	1.01 ± 0.12 b
JBB	27	1.00 ± 0.11 b

[1]$p < 0.0001$; Coefficient of variation: 13.47%. Statistical analysis (ANOVA) complemented Tukey's test at a 5% significance level (Montgomery, 2020).

Table 2. Absolute frequency (FA), relative frequency (FR), and relative frequency in percentage (FR%) of qualitative assays (presence and absence) of formaldehyde and rancidity in charqui (brands CA and CB) and jerked beef (brands JBA and JBB) samples.

Assay	Sample	Results	FA	FR	FR (%)
Formaldehyde	CA	Presence	0	0.0	0
		Absence	22	1.0	100
	CB	Presence	0	0.0	0
		Absence	22	1.0	100
	JBA	Presence	0	0.0	0
		Absence	27	1.0	100
	JBB	Presence	0	0.0	0
		Absence	27	1.0	100
Rancidity	CA	Presence	0	0.0	0
		Absence	22	1.0	100
	CB	Presence	0	0.0	0
		Absence	22	1.0	100
	JBA	Presence	0	0.0	0
		Absence	27	1.0	100
	JBB	Presence	0	0.0	0
		Absence	27	1.0	100

(13.55 g/100 g ± 0.46 g/100 g), JBA (14.04 g/100 g ± 1.02 g/100 g), and JBB (13.64 g/100 g ± 1.02 g/100 g) had significant differences ($p < 0.01$). The highest and most significant NaCl concentration was found in brand CA. The same was observed in Na+ content, with brand CA (5.74 g/100 g ± 0.61 g/100 g) having the highest significant concentration ($p < 0.01$) than brands CB (5.33 g/100 g ± 0.18 g/100 g), JBA (5.51 g/100 g ± 0.40 g/100 g), and JBB (5.36 g/100 g ± 0.46 g/100 g). However, the NO2- content was significantly higher ($p < 0.01$) in the JBA (5.55 ppm ± 1.71 ppm) and JBB (6.35 ppm ± 1.02 ppm) brands compared to the CA (0.00 ppm ± 0.00 ppm) and CB (0.00 ppm ± 0.00 ppm). The CV values were stable and homogeneous for the NaCl (7.71%) and Na+ (7.71%) calculations. The CV was unstable and heterogeneous for the NO2- assay data of the analyzed samples.

The results of the protein, carbohydrate, lipid, moisture, FMR, and calorie assays are shown in Table 4. The brands CA (18.64% ± 3.43%) and CB (16.91% ± 3.34%) presented mean protein values significantly lower ($p < 0.01$) than the brands JBA (28.09% ± 2.67%) and JBB (27.08% ± 4.32%). No significant carbohydrate content was detected in all evaluated brands ($p > 0.05$). However, the brands CA (21.02% ± 3.08%) and CB (21.77% ± 2.68%) had mean lipid values significantly higher ($p < 0.01$) than the brands JBA (10.36% ± 1.35%) and JBB (10.28% ± 1.28%). Brand CA (43.93% ± 1.35%) had a significantly lower moisture content ($p < 0.01$) compared to the other brands CB (45.98% ± 1.34%), JBA (46.06% ± 1.84%), and JBB (47.55% ± 3.71%). Regarding the FMR content, brand CA (16.41% ± 1.54%) had a significantly higher mean value ($p < 0.01$) than brands CB (15.35% ± 0.46%), JBA (15.49% ± 1.02%), and JBB (15.09% ± 1.02%). The brands CA (263.73 kcal/100 g ± 18.19 kcal/100 g) and CB (263.51 kcal/100 g ± 13.29 kcal/100 g) presented significantly higher mean calorie values ($p < 0.01$) compared to the brands JBA (205.62 kcal/100 g ± 10.98 kcal/100 g) and JBB (200.83 kcal/100 g ± 18.33 kcal/100 g). The CV values were stable and homogeneous for the protein (15.11%), lipid (14.13%), moisture (5.13%), FMR (6.91%), and calorie (6.72%) assays.

Table 3. Mean ± standard deviation of NaCl (g/100 g), Na+ (g/100 g), and NO2- (ppm) determinations of charqui (brands CA and CB) and jerked beef (brands JBA and JBB) samples.

Sample	n	NaCl (g/100 g)	Na^+ (g/100 g)	NO_2^- (ppm)
CA	22	14.61 ± 1.54 c[1]	5.74 ± 0.61 c[2]	0.00 ± 0.00 a[3]
CB	22	13.55 ± 0.46 ab	5.33 ± 0.18 ab	0.00 ± 0.00 a
JBA	27	14.04 ± 1.02 abc	5.51 ± 0.40 abc	5.55 ± 1.71 b
JBB	27	13.64 ± 1.02 b	5.36 ± 0.46 b	6.35 ± 1.02 b

[1]NaCl: $p = 0.00503$; CV: 7.71%; [2]Na^+: $p = 0.00503$; CV: 7.71%; [3]NO_2^-: $p < 0.05$; CV: 68.77%. Values followed by different letters in the same column differ significantly ($p < 0.05$). Statistical analysis (ANOVA) complemented with Tukey's test at 5% significance level (Montgomery, 2020).

4 DISCUSSION

Mediani et al. (2022) reported that lipid oxidation causes significant changes during food storage and manufacturing, leading to rancidity. Agüero et al. (2020) demonstrated that peroxide hydrogen can interfere with the organoleptic properties of products fermented meats, increasing rancidity due to lipid oxidation and discoloration of the final product. Mishra et al. (2017) stated that lipid oxidation can alter color, texture, aroma, and nutritional content of dry food. Lipid oxidation generally occurs during cooking and storage.

The level of ferrous ions in jerky is considerably elevated after drying due to the increase in iron heme and the breakdown of heme pigments, facilitating self-oxidation and resulting in rancidity (Mediani et al., 2022; Mishra et al., 2017; Van Buren et al., 2023; Zioud et al., 2023). In our experiment, the presence of rancidity was not detected in samples from CA, CB, JBA, and JBB. Amaral et al. (2018) stated that lipid oxidation may be related to protein denaturation, antioxidant degradation, and enzymatic activity.

According to our studies, the peroxide index test was higher in jerked beef samples (JBA: 1.01 mEq/kg ± 0.12 mEq/kg and JBB: 1.00 mEq/kg ± 0.11 mEq/kg) than in charqui samples (CA and CB: 0.35 mEq/kg ± 0.05 mEq/kg). Mishra et al. (2021) quantified the thiobarbituric acid content to evaluate the oxidative degradation of lipids in muscle foods. However, in this experiment, we used the determination of the peroxide index to quantify lipid oxidation by considering a procedure robust and practical in the laboratory routine. We suggest a detailed study comparing the two methods—peroxide index and thiobarbituric acid—to express lipid oxidation in charqui and jerked beef. Mishra et al. (2021) reported that lipid content oxidation increases with increasing fat content in food. Amaral et al. (2018) reported that pre-cooking meat also increases the value of lipid oxidation in dried meat products. Lim et al. (2012) stated that the value of thiobarbituric acid reactive substances is the most used indicator to determine the degree of lipid oxidation in meat products. Mishra et al. (2017) demonstrated that products based on dried meat have a higher lipid oxidation value than fresh and smoked meat products.

Table 4. Mean ± standard deviation of protein (%), carbohydrate (%), lipid (%), moisture (%), fixed mineral residue (FMR) (%), and calories (kcal/100 g) of charqui (brands CA and CB) and jerked beef (brands JBA and JBB) samples.

Analysis	CA	CB	JBA	JBB
Protein (%)	18.64 ± 3.43 a[1]	16.91 ± 3.34 a	28.09 ± 2.67 b	27.08 ± 4.32 b
Carbohydrate (%)	0.00 ± 0.00 a[2]	0.00 ± 0.00 a	0.00 ± 0.00 a	0.00 ± 0.00 a
Lipid (%)	21.02 ± 3.08 b[3]	21.77 ± 2.68 b	10.36 ± 1.35 a	10.28 ± 1.28 a
Moisture (%)	43.93 ± 1.35 a[4]	45.98 ± 1.34 b	46.06 ± 1.84 b	47.55 ± 3.71 b
FMR (%)	16.41 ± 1.54 b[5]	15.35 ± 0.46 a	15.49 ± 1.02 a	15.09 ± 1.02 a
Kcal/100 g	263.73 ± 18.19 b[6]	263.51 ± 13.29 b	205.62 ± 10.98 a	200.83 ± 18.33 a

[1]CV: 15.11%, $p < 0.01$; [2]$p > 0.05$; [3]CV: 14.13%, $p < 0.01$; [4]CV: 5.13%, $p < 0.01$; [5]CV: 6.91%, $p < 0.01$; [6]CV: 6.72%, $p < 0.01$. Statistical analysis (ANOVA) complemented with Tukey's test at 5% significance level (Montgomery, 2020).

In this experiment, the presence of formaldehyde was not detected in the samples from CA, CB, JBA, and JBB. Li and Deng (2023) also did not detect due to national standards in China that limit the formaldehyde content in products like meat. The authors assessed that the content should be as low as possible. Therefore, we need to highlight the risk and consider the carcinogenicity, teratogenicity, and mutagenicity of formaldehyde.

The most commonly added ingredient in dried meat products such as charqui and jerked beef is NaCl. The NaCl is essential not only as a seasoning for meat but also for its dehydrating effect in meat for preservation. There are several cases in which salt is used for dehydrating meat (Aykın-Dinçer et al., 2021; Barat et al., 2011; Dimakopoulou-Papazoglou & Katsanidis, 2017; Mediani et al., 2022; Yao et al., 2022). The salt together with water is a binary osmotic treatment, causing osmotic dehydration of the meat. In this treatment, water is removed from the meat in a non-thermal manner. High concentrations of NaCl in the osmotic or brine solution cause salt absorption from meat to increase and decrease in concentration and/or water activity (Aykın-Dinçer et al., 2021; Barat et al., 2011; Dimakopoulou-Papazoglou & Katsanidis, 2017). The present work showed that charqui (CA) had a high concentration of NaCl (14.61 g/100 g ± 1.54 g/100 g), Na+ (5.74 g/100 g ± 0.61 g/100 g), and a low moisture concentration (43.93 g/100 g ± 1.35 g/100 g) compared to the other brands evaluated. Therefore, these data demonstrated that the samples with high moisture content indicated a tendency towards smaller values for RMF, NaCl, and Na+.

Additives (nitrite, nitrate, potassium sorbate, and others) are added to jerky and meat products during processing, usually to achieve the desired color or as preservatives. Mediani et al. (2022) reported that nitrite is a common preservative used in meat products. Nitrite plays a role as a bacteriostatic agent and bacteriocidal. In cured meat products, nitrite is added as a strong inhibitor to anaerobic microbes, especially *Clostridium botulinum*. Furthermore, nitrite also acts as a colorant when added to meat products, as it is a strong heme oxidant. Generally, nitrite performs as a heme oxidizing agent in cured meat products to achieve the red color of typical meat products (Govari & Pexara, 2015; Martins & Graner, 2005; Sebranek & Bacus, 2007). In this experiment, samples of jerked beef (JBA and JBB) presented higher peroxide index and nitrite values than charqui samples (CA and CB). The high water and nitrite concentrations and low RMF and NaCl concentrations in jerked beef samples (JBA and JBB) corroborate the increase in lipid oxidation compared with the other samples evaluated in the study (CA and CB). This demonstrates that chemical interferents (H_2O, NO_2-, and NaCl) react simultaneously on the meat product resulting in increased lipid content oxidation in jerked beef samples than in charqui samples. For a conclusive definition, more scientific study is needed to evaluate these chemical interferences in dry and salted meat products (charqui and jerked beef).

The proximate composition is linked to the moisture content, protein, ash, and carbohydrate in charqui and jerked beef products. It is essential to observe the amount of proximate composition to ensure that the drying process technology produces the best quality of charqui and jerked beef (Ferreira et al., 2013; Mediani et al., 2022). The proximate analysis provides a comparison between the technological process of drying dried meat based on specific nutrients. The drying process has an impact on the total moisture content and fat content of dried meat products (Zdanowska-Sasiadek et al., 2018). Mishra et al. (2017) reported that the process of drying causes a reduction in moisture and total fat contents. Ferreira et al. (2013) evaluated that the addition of condiments such as NaCl to jerky products can raise the RMF level while decreasing the level of product moisture. In this experiment, we observed high moisture and protein concentrations in jerked beef samples. In charqui samples, the high levels found were lipids, RMF, and calories. In the methodology used for carbohydrate, we did not detect levels greater than zero percent in both charqui and jerked beef samples. In what concerns high levels of NaCl and RMF, this research corroborates the data presented by Ferreira et al. (2013), demonstrating the decrease in moisture content in charqui samples.

5 CONCLUSION

The rigorous scientific methodology employed in this study yielded significant insights, leading to the following key findings:

- Jerked beef samples exhibited elevated levels of lipid oxidation, as indicated by peroxide index measurements;
- Notably, no evidence of rancidity or formaldehyde formation was detected in either charqui or jerked beef samples;
- Charqui samples displayed elevated concentrations of trimethylamine, lipids, calories, sodium chloride (NaCl), and sodium ions (Na+);
- Conversely, jerked beef samples exhibited high concentrations of proteins, moisture, and nitrite;
- It is plausible that the observed heightened levels of moisture and nitrite content contributed to the lipid oxidation noted in jerked beef samples;
- Furthermore, the presence of elevated NaCl concentrations in charqui samples appeared to exert an inhibitory effect on lipid oxidation activity.

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