




ORIGINAL RESEARCH

Physicochemical composition, lipid oxidation, and microbiological quality of ram mortadella supplemented with *Smallanthus sonchifolius* meal

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Abstract

This study evaluated the physicochemical, lipid peroxidation, and microbiological quality of mortadellas prepared with ram and supplemented with different amounts of *Smallanthus sonchifolius* meal. Three mutton mortadella formulations supplemented with 1.25%, 2.50%, and 5% yacón meal and control formulation without yacón meal was included. The physicochemical, lipid peroxidation, and microbiological analyses were carried out in the time periods 10, 45 days, three, and six month after the preparation of mortadella. The control formulation presenting lighter and more intense red tone compared with the other formulations. All formulations presenting lipid peroxidation increased 90 days after processing; already the pH and Aw values were constant for all formulations at the experimental times stipulated. All formulations had the physicochemical characterization and microbiological quality standards, according to defined in regulations for mortadella production in Brazil. The results show that mutton mortadella supplemented with yacón meal is a promising alternative in the manufacture of healthy meat products.

KEYWORDS

food safety, fructooligosaccharides, lamb, meat products

1 | INTRODUCTION

Aiming to meet the demands and preferences of increasingly health-conscious customers, a considerable number of studies currently addresses the development of more healthy foods (Biswas, Kumar, Bhosle, Sahoo, & Chatli, 2011; Vidal et al., 2012; Cardoso, Henry, Almeida, Ferreira, & Ladeira, 2013; Doménech-Asensi et al.,

2013; Maia Junior et al., 2013). In this scenario, much research has been dedicated to conceive innovative formulations of meat products. More specifically, such innovation efforts are directed toward the development of products that may be considered functional, that is, foods that exert beneficial health effects in addition to nutrition potential, becoming useful alternatives in the prevention and treatment of diseases (Dutra et al., 2013; Leite et al., 2015;

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Méndez-Zamora et al., 2015; Viuda-Martos, Ruiz-Navajas, Fernández-López, & Pérez-Álvarez, 2010; Yetim, Gokalp, Kaya, Yanar, & Ockerman, 1992).

Mortadella is one of the most consumed cooked sausages by the world population, being processed using mainly pork, but it can be made from meat of various species. Today mutton emerges as a feasible alternative on development from coated with skin stuff owing to the great nutritional and sensory quality besides the fact that it is not the object of religious restrictions. Mutton has high levels of protein and ironwork and suitably lower levels of fat, compared with other meat kinds, gaining preference as ingredient of healthier skin-encased products (Lima Júnior, Rangel, Urbano, & Moreno, 2013; Osório, Osório, & Sañudo, 2009). Several studies are investigating the incorporation of sheep or goat meat in sausages and the use of natural antioxidants as protective factors against lipid oxidation. A study was conducted using different levels of pork fat in goat mortadella (Guerra et al., 2011), using jaboticaba peel extract at 0.5%, 0.75%, and 1.0% showed high antioxidant power (Almeida et al., 2015), using tomato paste increased product stability and shelf life by significantly reducing lipid oxidation associated with storage (Doménech-Asensi et al., 2013), and using fruit aqueous extract of the Brazilian pepper tree in fresh pork sausage that best resisted lipid peroxidation (Oliveira et al., 2020).

The main strategy used by the meat industry to inhibit lipid oxidation is the addition of antioxidants to meat and meat products (Cunha et al., 2018; Echegaray et al., 2018; Gómez et al., 2018; Lorenzo et al., 2018; Pateiro et al., 2018; Zamuz et al., 2018). However, nowadays consumers demand more natural products, which limits the industry in their use of currently allowed synthetic antioxidants in foods, leaving manufacturers with few options (Barden & Decker, 2016). As a source of bioactive compounds like fructooligosaccharides, inulin, and phenolic compounds, the flour obtained from the tuberous root yacón (*Smallanthus sonchifolia*) stands as an alternative on fabrication to healthful skin-encased products and is now considered a functional food (Delgado, Tashiro, Maróstica Júnior, & Pastore, 2013; Ojansivu, Ferreira, & Salminen, 2011). The explanation is that the human body makes not yield enzymes which metabolize fructooligosaccharides, which therefore goes through the stomachic track unmetabolized, providing small energy levels and becoming a promising ingredient in foods to obese individuals with associated transmissible diseases (Borges et al., 2012). In addition, it should be highlighted that yacón meal is produced by dehydration, which makes it even more interesting as a food ingredient due to the resulting increased shelf life and the possibility to add it as supplement to a variety of other foods.

Like any other food, the quality of meat products is assessed based on sensory, physicochemical, and microbiological attributes. Yet, percent composition, instrumental analyses that include pH, water activity (Aw), color, and texture, as well as the determination of lipid oxidation level also are important parameters supplying essential information concerning nutritional quality and as well checking the shelf life of the product (Gomes & Oliveira, 2011). For example, as one of the chemical reactions most often observed in foods, lipid

peroxidation is the main cause behind the deterioration of several food products. These reactions are triggered by contact with oxygen, when electrons are transferred between molecules and free radicals are produced, oxidizing lipids. The list of negative outcomes of lipid peroxidation includes undesired changes in flavor, smell, overall appearance, physical attributes, and nutritional value, besides shorter shelf life. Levels of thiobarbituric acid (TBARS) are the main parameter to measure lipid peroxidation in foods (Araújo, 2011).

The control of microbiological contamination is key to guaranteeing consumer safety and establishing a food product's shelf life. Importantly, like any other food product, mortadella is subject to the action of harmful microorganisms, some of which are pathogenic, which reduces shelf life and increases the risk of food-borne diseases (Franco & Landgraf, 2005). In addition, there is a nutritional loss that leads to the formation of toxic substances, so the control of oxidative processes is of vital importance for the meat industry (Domínguez et al., 2019).

On these bases, study proposes to evaluate the possible effects of storage on the quality of mortadella formulations made with ram and supplemented with different amounts of *Smallanthus sonchifolius* meal at several stages of the production process.

2 | MATERIALS AND METHODS

2.1 | Raw materials

The mutton shoulder cuts used were from Santa Inês and Dorper sheep bred in confinement. All animals were slaughtered in a commercial slaughterhouse (Atílio Vivácuqua, ES, Brazil) which is inspected by the State Inspection Service.

Mutton cuts were stocked in a freezer at -18°C upon the production in mortadellas. *Smallanthus sonchifolius* meal and the some other ingredients used in formulations were purchased on specialized stores selling native crop products and chemical additives for skin-encased products.

2.2 | Mortadellas of ram

Four experimental mortadella formulations (F1, F2, F3, Control) were prepared with mutton and different amounts of yacón meal. Four replicates were performed for each formulation.

Preliminary assays and a review of current regulations regarding food quality and identity standards were conducted to define the percent composition of raw materials and other additives in addition to fat reduction percent values and the respective amounts of yacón meal supplemented to mortadella formulations (Allais, 2010; Brasil, 2000; Guerra et al., 2012; Yetim et al., 1992). Percent composition of formulations is presented as percent raw material and additives values on Table 1.

Mortadella formulations were processed according as Guerra et al. (2011) with alterations. Initially, the raw material was allowed

TABLE 1 Formulations used in the elaboration of mutton mortadella supplemented with *Smalanthus sonchifolius* meal

Raw material	Control	F1	F2	F3
Mutton	67.00	67.00	67.00	67.00
Fat	30.00	27.00	24.00	21.00
Yacón meal ^a	0.00	1.25	2.50	5.00
Sugar ^b	0.10	0.10	0.10	0.10
Salt (NaCl) ^c	2.10	2.10	2.10	2.10
Sodium nitrite ^d	0.20	0.20	0.20	0.20
Emulsifier ^e	0.30	0.30	0.30	0.30
Color fixer ^f	0.30	0.30	0.30	0.30
Water	0.00	1.75	3.50	4.00

^aNatural Life[®] yacón meal.

^bUnião[®] sugar.

^cCisne[®] salt.

^dKura K007 - Doremus[®] curing salt.

^eIbrac[®] emulsifier.

^fIbrac[®] color fixer.

to thaw in a BOD incubator (Eletrolab EL101/3 250W, Eletrolab, São Paulo, SP, Brazil) at $4 \pm 0.5^\circ\text{C}$. After thawing, ram and pork grease were ground using a beef grinding machine (Caf 8 Inox) withal grind plates with 8-mm, 5-mm, and 3-mm disks. Immediately after mutton, pork grease, *Smalanthus sonchifolius* meal, and the some other additives were weighted and mixed on a multiprocessor (Philips RI7636 750W) for approximately 6 min upon complete homogenization of the material. After processing, the formulations were separated and packed in polyethylene bags to cook mortadella.

The samples were cooked on an stainless steel former on an dual bathe at 80°C to the temperature in the middle of mass achieve 74°C . Mortadellas were separated, tagged, vacuum-packed (Selovac 200-B, São Paulo, SP, Brazil) in polyethylene bags at $4 \pm 0.5^\circ\text{C}$ until analysis and shelf-life estimation during 120 days after processing.

2.3 | Physicochemical characterization

Four samples from each one formulation were ground, combined, and used in the following analyses: (a) moisture (difference between the weights of the samples before and after drying in a stove at 105°C), (b) mineral matter, (c) protein concentration (classic Kjeldahl method), (d) fat content (direct Soxhlet method), (e) dietary fiber (acid digestion and gravimetric analysis), and (f) non-nitrogen content (by subtraction). All analyses were carried as recommended by to Cechi (1999) and AOAC (2000).

2.4 | Water activity, pH, and mortadella color

Mortadella subsamples were inserted into the container (with a capacity of 15 ml) of Aqualab (Decal Devices Inc.) water activity analyzer (Aw), which uses the dew point principle. In the pH analyses, a

10-g sample of mortadella was first homogenized in 100 ml distilled water with shaking for 5 min, and pH was determined in a potentiometer (Schott Handylab).

Color (lightness— L^* ; redness— a^* ; and yellowness— b^*) was determined immediately after the samples were processed, using a colorimeter (Minolta CR-400; Konica Minolta Sensing, Inc., Osaka, Japan) (settings: diffuse illumination/ 0° viewing angle, illuminant D65, specular component included) calibrated to a white standard. The raw samples were cut in half and the equipment was placed at three different points in the mortadella mass. The saturation index was calculated using the equation $C^* = (a^{*2} + b^{*2})^{1/2}$.

2.5 | Lipid peroxidation

TBARS levels indicate lipid peroxidation. Thiobarbituric acid is used to quantify levels of malondialdehyde (MDA), a short-chain aldehyde formed by the decomposition of lipid hydroperoxides produced by oxidation reactions. The analyses of mortadella formulations were carried out according to the methodology described by Vyncke (1970) and modified by Sorensen and Jorgensen (1996). Readings were conducted in a spectrophotometer (UV-5100, Kasuaki) at 532 nm against a concentration (x):absorbance (y) curve of 1,1,3,3-tetraethoxypropane, used as standard. Values were expressed as mg MDA/kg.

2.6 | Microbiological analyses

Microbiological analysis of the samples was performed, according to Silva Junqueira & Silveira (2007). The results were compared with the standards recommended in the RDC 12 (Brasil, 2001), for coliforms at 45°C (Most Probable Number method), Coagulase-positive *Staphylococcus* (Presence or absence), *Salmonella* spp. (presence or absence) and sulfite-reducing clostridia at 46°C .

2.7 | Statistical analyses

The data obtained in the physicochemical analyses were analyzed as a completely randomized experimental design with four treatments and three repeats each. The results were submitted to analysis of variance (ANOVA) at 5% probability. The treatments were compared by the Student–Newman–Keuls test (SAS, 2009 version 9.2).

3 | RESULTS AND DISCUSSION

Mean chemical composition of mortadellas (humidity, total protein, lipid, ash, dietary fiber, and non-nitrogen content) of ram mortadella formulations are presented in Table 2.

Moisture values varied between 54.60% and 56.40%, proteins from 16.00% to 18.80%, fat between 20.13% and 25.10%, ash

Parameters	Formulations			
	Control	F1	F2	F3
Moisture (%)	56.40 ± 0.10 ^a	55.00 ± 0.10 ^b	55.16 ± 0.15 ^b	54.60 ± 0.15 ^c
Proteins (%)	16.00 ± 0.00 ^c	18.23 ± 0.06 ^b	18.43 ± 0.40 ^{ba}	18.80 ± 0.10 ^a
Fat (%)	25.10 ± 0.10 ^a	23.73 ± 0.15 ^b	22.03 ± 0.38 ^c	20.13 ± 0.15 ^d
Ash (%)	2.50 ± 0.00 ^b	2.50 ± 0.00 ^b	2.60 ± 0.00 ^b	3.10 ± 0.10 ^a
Dietary fiber (%)	0.00 ± 0.00 ^d	0.30 ± 0.00 ^c	0.40 ± 0.00 ^b	1.13 ± 0.06 ^a
Non-nitrogenated content (%)	0.00 ± 0.00 ^d	0.24 ± 0.06 ^c	1.38 ± 0.06 ^b	2.24 ± 0.06 ^a
Yield (%)	67.83 ± 1.05 ^b	68.30 ± 1.20 ^b	72.06 ± 3.05 ^a	73.70 ± 1.10 ^a

*Values followed by different lowercase letters on the same line indicate statistically significant differences ($p < .05$) in the Student-Newman-Keuls test.

Parameters/days	Formulations			
	Control	F1	F2	F3
L*				
10 days	59.84 ± 0.34 ^{Aa}	56.02 ± 1.60 ^{Ab}	54.34 ± 0.69 ^{Ac}	51.03 ± 0.20 ^{Ad}
45 days	60.18 ± 0.67 ^{Aa}	56.86 ± 0.19 ^{Ab}	55.14 ± 0.47 ^{Ac}	51.41 ± 0.32 ^{Ad}
90 days	58.35 ± 0.16 ^{Ba}	54.10 ± 1.51 ^{Bb}	51.73 ± 0.63 ^{Bc}	50.30 ± 0.31 ^{Bd}
120 days	55.57 ± 1.48 ^{Ca}	55.68 ± 1.68 ^{Ba}	52.38 ± 0.80 ^{Bb}	50.12 ± 0.21 ^{Bc}
a*				
10 days	12.13 ± 0.04 ^{Aa}	11.42 ± 0.20 ^{Ab}	10.59 ± 0.03 ^{Ac}	9.97 ± 0.11 ^{Ad}
45 days	12.09 ± 0.21 ^{Aa}	10.84 ± 0.13 ^{Bb}	10.13 ± 0.18 ^{Bc}	8.26 ± 0.15 ^{Bd}
90 days	11.90 ± 0.12 ^{Aa}	10.95 ± 0.06 ^{Bb}	10.37 ± 0.12 ^{Bc}	7.89 ± 0.09 ^{Cd}
120 days	11.97 ± 0.21 ^{Aa}	9.79 ± 0.15 ^{Cb}	8.63 ± 0.06 ^{Cc}	6.56 ± 0.38 ^{Dd}
b*				
10 days	12.37 ± 0.37 ^{Ad}	13.35 ± 0.18 ^{Ac}	14.27 ± 0.31 ^{Ab}	16.11 ± 0.27 ^{Aa}
45 days	12.10 ± 0.30 ^{Ac}	13.50 ± 0.34 ^{Ab}	14.01 ± 0.12 ^{Aa}	14.07 ± 0.17 ^{Ba}
90 days	12.24 ± 0.17 ^{Ac}	13.07 ± 0.15 ^{Ab}	14.20 ± 0.31 ^{Aa}	12.75 ± 1.28 ^{Cb}
120 days	12.04 ± 0.44 ^{Ab}	12.92 ± 0.34 ^{Aa}	12.63 ± 0.15 ^{Ba}	11.89 ± 0.82 ^{Cc}
c*				
10 days	17.41 ± 0.30 ^{Ab}	17.54 ± 0.24 ^{Ab}	17.81 ± 0.28 ^{Ab}	18.94 ± 0.29 ^{Aa}
45 days	17.10 ± 0.35 ^{Aa}	17.39 ± 0.23 ^{Aa}	17.58 ± 0.27 ^{Aa}	16.33 ± 0.21 ^{Bb}
90 days	16.94 ± 0.42 ^{Ab}	16.99 ± 0.05 ^{Bb}	17.29 ± 0.14 ^{Aa}	15.00 ± 0.41 ^{Cc}
120 days	16.19 ± 0.20 ^{Ba}	16.21 ± 0.35 ^{Ca}	15.30 ± 0.08 ^{Bb}	13.59 ± 0.42 ^{Dc}

*Values followed by different capital letters in the same column and values in lowercase letters on the same line indicate statistically significant differences ($p < .05$) in the Student-Newman-Keuls test.

between 2.50% and 3.10%, fiber from zero to 1.13%, and non-nitrogenated contents ranged from zero to 2.24%. The results show that the use of fat in formulations affected moisture, protein, and fat content values significantly ($p < .05$) between mortadella formulations.

On the whole, moisture values decreased with higher yacón meal percent values and lower fat levels in formulations. Leite et al. (2015) also observed that frankfurters with high moisture values were prepared with the lowest fat contents. Regarding the moisture content, it is worth noting that the use of potato yacón flour was

TABLE 2 Physicochemical parameters and yield (mean ± standard deviation) of mortadella formulations prepared with mutton and supplemented with different amounts of *Smilax glabra* meal

TABLE 3 Color (means ± standard deviation) of mortadella formulations prepared with mutton and supplemented with different amounts of *Smilax glabra* meal after different storage periods

proportionally higher in the formulations F1, F2, and F3, and the proportional addition of water in these formulations was necessary in order to avoid changes in the texture of the samples due to the high capacity of water retention (WHC) of yacón potato flour. Moisture contents in all samples were beneath the 65% maximum admissible level established in Brazilian regulations.

Despite the statistically significant differences in protein levels between formulations ($p < .05$), every met the minim 12% value stated in Brazilian legislation. How stabilizing agent in the

TABLE 4 TBARS of mortadella formulations prepared with mutton and supplemented with different amounts of *Smallanthus sonchifolius* meal after different storage periods

Parameters/days	Formulations			
	Control	F1	F2	F3
10 days	0.007 ± 0.00 ^{Dc}	0.011 ± 0.00 ^{Db}	0.012 ± 0.00 ^{Bb}	0.013 ± 0.00 ^{Ba}
45 days	0.010 ± 0.00 ^{Cd}	0.019 ± 0.00 ^{Cc}	0.021 ± 0.00 ^{Ab}	0.028 ± 0.00 ^{Aa}
90 days	0.031 ± 0.00 ^{Ba}	0.031 ± 0.00 ^{Ba}	0.021 ± 0.00 ^{Ac}	0.027 ± 0.00 ^{Ab}
120 days	0.070 ± 0.00 ^{Aa}	0.043 ± 0.00 ^{Ab}	0.022 ± 0.00 ^{Ad}	0.027 ± 0.00 ^{Ac}

*Values followed by different capital letters in the same column and values in lowercase letters on the same line indicate statistically significant differences ($p < .05$) in the Student–Newman–Keuls test.

elaboration of emulsified products, proteins, are active on the lipid–water interface, cutting interface pressure, and enriching mixing to ingredients. Proteins also prevent the coalescence and loss of lipids, playing an essential role concerning acceptable sensory traits of emulsified skin-encased products (Guerra et al., 2012).

Fat levels also differed significantly between formulations ($p < .05$). Although this result was expected due to the decreasing amounts used in F1, F2, and F3, in that order, all formulations met the 30% maximum admissible level defined on Brazilian norms (Brasil, 2000). For Guerra et al. (2012), fat levels are extremely important to ensure that the product will have its peculiar sensory traits, directly affecting texture and taste.

The results of the study also show as increasing amounts of yacón meal induced significant differences ($p < .05$) in ash, dietary fiber, and non-nitrogenated contents, improving yield of all formulations, compared with the control, that did not added *Smallanthus sonchifolius* meal. According to Mendoza, García, Casas, and Selgas (2001) and Barreto Pacheco & Pollonio (2015), the addition of dietary fiber to meat products may improve yield, reducing costs of a formulation, improving texture, and influencing rheological and sensory behavior, especially appearance and color.

Overall, the percent composition of the formulations developed in the present study is similar in the data acquired in various cooked skin-encased products prepared with mutton and *Smallanthus sonchifolius* meal and flour of some other vegetables (Huang, Tsai, & Chen, 2011; Dutra et al., 2013; Barreto, Pacheco, & Pollonio, 2015; Contado, Rocha, Queiroz, Abreu, & Ramos, 2015; Santos Júnior et al., 2017).

The variation of pH of mortadella formulations prepared with mutton and *Smallanthus sonchifolius* meal 120 days behind processing varied between 5.86 and 6.11. Overall, all formulations exhibited similar pH curves. Interestingly, A_w values did not vary statistically between formulations throughout the experiment, remaining constant at 0.97 ($p > .05$). For Guerra et al. (2011), pH and A_w are important quantitative parameters in cooked skin-encased meat products, since high values promote the development of undesired microorganisms, while low figures affect texture and flavor negatively.

The color curves of formulations constructed with data obtained on days 10, 45, 90, and 120 days after processing are shown in Table 3.

In the color analysis, L^* values (which represent luminosity; 0 = black, 100 = white) of formulations differed statistically ($p < .05$). The results show that the highest the quantity of *Smallanthus sonchifolius* meal admixed, the murker were the mortadella formulations. While F3, which was prepared with the highest amount of yacón meal exhibited the murkest color, the control formulation (with no yacón meal) presented the lightest. It was also observed that all formulations became mildly darker as experimental time advanced, with statistically significant differences ($p < .05$) 90 days after processing.

Also, the admixture of different fat levels also affected color, making lighter mortadella, which may therefore explain the differences in L^* values observed for formulations. Sánchez-Rodríguez (2001) claimed that water and lipid contents may affect L^* values considerably, as observed in the present study. For example, the control formulation, which contained no yacón meal and had the highest amount of added fat, presented the lightest hue.

Indicating intensity of red hues, a^* values differed between samples throughout the experiment ($p < .05$). This difference was directly proportional to the amount of yacón meal added to each formulation, when high yacón meal contents produced lighter mortadella. Moreover, the redness decreased in all experimental formulations with time and differed statistically from the control formulation ($p < .05$).

Statistically significant difference ($p < .05$) was also observed for b^* values between formulations during the experiment. The highest the quantity of *Smallanthus sonchifolius* meal added, the highest the b^* values of formulations were. But a decrease in b^* values was also observed, only for F2 and F3 on days 120 and 45 after processing. It should be highlighted that b^* values express intensity of yellow color. Yet, in the analysis of meat products the parameter represents brown hues (Barreto, Pacheco, & Pollonio, 2015). Thus, F2 and F3, which were made with the intermediate and the high contents of *Smallanthus sonchifolius* meal, respectively, presented rather intense brown hues. The effect of redness and yellowness gets rather apparent when the parameters are measured based on the saturation index, C^* . Overall, C^* values decreased ($p < .05$) for all formulations during 120 days into storage.

For Zeola Souza Souza Silva Sobrinho & Barbosa (2007), color of skin-encased products is the most important quality parameter the consumer assesses as of purchase, determining the choice made. Overall, the control formulation did was the light

and reddest, while the other formulations became darker and lost intensity of red color with time, that can affect sensory acceptability. However, the overall color effects acquired were like, as observed by Contado Rocha Queiroz Abreu & Ramos (2015) in a investigation which tested ham-like meat products formulated with *Smallanthus sonchifolius* meal.

The TBARS values of the mortadella formulations prepared and analyzed in the present study are shown in Table 4.

The parameter is the most commonly used to determine lipid peroxidation in meat products, when MDA levels in samples reach between 0.5 mg/kg and 2.0 mg/kg. MDA levels in mortadella formulations remained constant until day 10 after processing, with no statistically significant differences ($p > .05$). Starting on day 90 into storage, TBARS levels increased in all formulations. But on day 120, TBARS levels of F1 and the control formulation were significantly higher ($p < .05$) compared with F2 and F3, which were prepared with the intermediate and high levels of yacón meal used in this study.

Despite the variation in lipid peroxidation levels, the TBARS values obtained indicate that the addition of yacón meal did not significantly influence the fast oxidative changes observed in products soon after processing. But 120 days after processing, F2 and F3 had lower TBARS values, showing that yacón meal may in fact be a useful ingredient to prevent oxidative changes during the storage of mortadella.

Lipid peroxidation is an inevitable chemical phenomenon observed during the storage of meat products. However, it may be inhibited adding antioxidants that lend greater stability, preventing the oxidative rancidness of fats and changes in sensory attributes. In this sense, yacón meal is an interesting source of phenolic compounds, mainly chlorogenic acid, which may play an antioxidant role (Santana & Cardoso, 2008). Furthermore, the antioxidant power of phenolic compounds has been associated with the hydroxyl group bound to the aromatic ring, to which it donates the electrons of its hydrogen atom, neutralizing free radicals (Radha Krishnan et al., 2014).

The results of the present study are similar to those published by Teixeira (2010) that confirmed the antioxidant effect of yacón meal in ham-like skin-encased products. For Wu Duckett Neel Fontenot & Clapham (2008) and Prior et al. (2003), this antioxidant effect of yacón meal is induced by heating or cooking mortadella formulations, which in turn promotes proteolysis. In addition to that, the actual proteins present in mortadella formulations may have antioxidant effect as well. For example, the dipeptide carnosine has a hydrophilic group whose antioxidant activity is comparable to that of ferulic acid, a phenolic compound. It may therefore be assumed that the proteolysis reactions occurring during storage are behind the similar antioxidant activity of samples of mortadella formulations in the present study. The exceptions were F1 and the control formulation, which had higher antioxidant activity values on day 120 after processing. It should be emphasized that these formulations

Parameters	Time	Formulations				Regulations ^c
		Control	F1	F2	F3	
Thermotolerant coliforms ^a	10 days	<0.3	<0.3	<0.3	<0.3	<10 ³
	45 days	<0.3	<0.3	<0.3	<0.3	<10 ³
	90 days	<0.3	<0.3	<0.3	<0.3	<10 ³
	120 days	<0.3	<0.3	<0.3	<0.3	<10 ³
Coagulase-positive <i>Staphylococcus</i> ^b	10 days	<1.0	<1.0	<1.0	<1.0	3 × 10 ³
	45 days	<1.0	<1.0	<1.0	<1.0	3 × 10 ³
	90 days	<1.0	<1.0	<1.0	<1.0	3 × 10 ³
	120 days	<1.0	<1.0	<1.0	<1.0	3 × 10 ³
Sulfite-reducing <i>Clostridium</i> at 46°C ^b	10 days	<1.0	<1.0	<1.0	<1.0	5 × 10 ²
	45 days	<1.0	<1.0	<1.0	<1.0	5 × 10 ²
	90 days	<1.0	<1.0	<1.0	<1.0	5 × 10 ²
	120 days	<1.0	<1.0	<1.0	<1.0	5 × 10 ²
<i>Salmonella</i> sp.	10 days	absent	absent	absent	absent	absence
	45 days	absent	absent	absent	absent	absence
	90 days	absent	absent	absent	absent	absence
	120 days	absent	absent	absent	absent	absence

TABLE 5 Microbiological analysis (means ± standard deviation) of mortadella formulations prepared with mutton and supplemented with different amounts of *Smallanthus sonchifolius* meal after different storage periods

^aGiven as most probable number (MPN) per gram

^bGiven as colony forming units (CFU) per gram

^cBRASIL. 2001.

contained comparatively high levels of fat, making them more vulnerable to lipid peroxidation.

Plant-based curing agents have been signaled as an alternative replacement of chemical additives in cured food products (Santamaria, 2006). One of the advantages of plant extracts is the ability to improve quality and shelf life of products with no need for other additives. The antioxidant effect of these compounds stabilizes fat, preventing rancidness. In addition, this effect is equivalent to that exhibited by conventional, commercial products, making them a healthier ingredient of meat products.

Mean bacterial counts of thermotolerant coliforms, coagulase-positive *Staphylococcus*, sulfite-reducing *Clostridium*, and *Salmonella* sp. are shown in Table 5.

Mortadella is a cooked meat product with a shelf life of 60 days when stocked at 4°C. In the actual study, every microbiological count was below the maximum admissible amounts determined by Brazilian norms 120 days in storage. Such results are likely to what has been noticed in some other works (Cardoso et al., 2013; Guerra et al., 2011; Brasil, 2001).

The good microbiological quality of the mortadella formulations analyzed is an immediate result of the virtue of the raw materials used, beyond the introduction of good production practices, the utilization of additives that avoid the growing of deleterious microorganisms, and the vacuum-packaging process employed to mortadellas.

Brazilian regulations require the use of curing salts like potassium or sodium nitrite or nitrate, for instance, in the formulations of meat products to ensure microbiological safety, reduce lipid and protein peroxidation, and improve sensory attributes. But curing agents, like compounds present in yacón meal, for instance, also play a role in the color of mortadella formulations and are used together with antioxidants improve flavor, maintaining sensory quality, and prolonging shelf life (Brasil, 2000; Pardi, Santos, Souza, & Pardi, 1996).

All formulations had the physicochemical characterization and microbiological quality standards defined in regulations for mortadella production in Brazil. The color of the control formulation was lighter and had a* tone more intense, compared with the other formulations, which became darker and less red with time. All formulations presenting lipid peroxidation increased 90 days after processing, already the pH and Aw values were constant for all formulations at the experimental times stipulated. The results show that mutton mortadella supplemented with yacón meal is a promising alternative in the manufacture of healthy meat products. It is worth noting that projects involving partnerships between research centers and the food industries become a necessity for the search for innovations, aiming to meet the demands of consumers for healthier products and make them available on a commercial scale.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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