Sensory and physicochemical evaluation of low-fat chicken mortadella with added native and modified starches

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Abstract The objective of this work was to evaluate the effect of adding different starches (native and modified) on the physicochemical, sensory, structural and microbiological characteristics of low-fat chicken mortadella. Two formulations containing native cassava and regular corn starch, coded CASS (5.0 % of cassava starch) and CORN (5.0 % of regular corn starch), and one formulation produced with physically treated starch coded as MOD1 (2.5 % of Novation 2300) and chemically modified starch coded as MOD2 (2.5 % of Thermtex) were studied. The following tests were performed: physicochemical characterization (moisture, ash, protein, starch and lipid contents, and water activity); cooling, freezing and reheating losses; texture (texture profile test); color coordinates (L^* , a^* , b^* , C and h); microbiological evaluation; sensory evaluation (multiple comparison and preference test); and histological evaluation (light microscopy). There was no significant difference ($p>0.05$) for ash, protein, cooling loss, cohesiveness or in the preference test for the tested samples.

The other evaluated parameters showed significant differences ($p<0.05$). Histological study allowed for a qualitative evaluation between the physical properties of the food and its microscopic structure. The best results were obtained for formulation MOD2 (2.5 % Thermtex). The addition of modified starch resulted in a better performance than the native starch in relation to the evaluated technological parameters, mainly in relation to reheating losses, which demonstrated the good interaction between the modified starch in the structure of the product and the possibility of the application of this type of starch in other types of functional meat products.

Keywords Fat substitutes · Light microscopy · Functional food · Texture · Sensory evaluation

Introduction

Developing low-fat meat products is a huge challenge for the food industry (Zhang et al. 2010; Furlán et al. 2014) because, in general, reducing fat results in increasing the meat proportion in formulations and as a consequence costs rise considerably. In addition, the red color becomes more intense, hardness increases, and the water binding capacity decreases (Weiss et al. 2010; Brewer 2012); the sensory quality is also impaired, which decreases the acceptability of the meat product.

Searching for technological solutions, several hydrocolloids (polysaccharides and proteins) have been tested as fat replacers (Bloukas et al. 1997; Choe et al. 2013; Furlán et al. 2014; Keenan et al. 2014; Kumar and Sharma 2004; Marchetti et al. 2014; Modi et al. 2009; Weiss et al. 2010). Among polysaccharides, starch is one of the most used because it has high water-binding capacity, which contributes to improvement in the stability and texture of products (Petracci

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et al. 2013). Starches from different sources can be used; native, modified or partially hydrolyzed.

Native starches are commercially extracted from several raw materials, such as corn, potatoes, cassava, rice and wheat, and they have different proportions of amylose and amylopectin, which results in different technological properties. Amylose and amylopectin are homopolymers that only have D-glucose as the constituent monomer (Damoradan et al. 2010); due to differences in the glycosidic bonds and in the molar mass, the two polymers (linear or branched) present distinct technological properties (Petracci et al. 2013).

In the Brazilian meat processing industry, the preferred starch is that which is extracted from cassava (Pedroso and Demiate 2008) due to a neutral flavor, availability, relatively low cost and a low gelatinization temperature that is compatible with the cooking temperatures of most meat products, such as sausages, mortadella and formed ham.

Modified starches are developed as an alternative to native ones and they offer superior performance (mainly water-binding capacity, swelling, viscosity) and improvements in the final product quality, mainly in terms of texture and juiciness. Several chemical and physical treatments of starch granules can promote changes in hydrogen bonds, which consequently affect the functionality of the starch. These modified starches are generally more thermostable and less sensitive to shear stress and to syneresis, which are common constraints on the use of native starches; they are also known to mimetize fat improving texture (Petracci et al. 2013).

There have been some studies where modified starches were reported as being better than native starches when applied in emulsions (Zhang and Barbut 2005; Song et al. 2010; Moghaddam et al. 2013 and Timgren et al. 2013). In Brazil, due to high costs and also a lack of knowledge about technological advantages, modified starches are not widely used in the meat processing sector. On the other hand, there is a growing demand for low-fat, healthier meat products, which makes it necessary to be aware of better alternatives as well as new ingredients and additives.

An emulsion is formed by two immiscible liquids, one disperse in another, in the form of small droplets. The droplets are known as disperse phase whereas the other is named continuous phase (McClements 2005). Meat emulsions are considered a mixture where the meat constituents, finely grinded, are dispersed in a similar manner of a fat-water emulsion; the discontinuous phase is fat and the continuous phase is made of an aqueous solution of salts and proteins. Mortadella and sausages are classified as emulsified products.

The Mortadella Bologna is a traditional Italian food produced with poor cuts of pork and other non-meat raw materials. It is most produced in North and Central Italy and is under Mortadella PGI (Protected Geographical Indication) regulation (Barbieri et al. 2013). In Brazil mortadella is

defined as a processed meat product produced as an emulsion of meat, with or without addition of lard, other ingredients embedded in natural or artificial casings and cooked properly (MAPA 2000). In the Brazilian market the mortadellas are classified in: Mortadella, Bologna-type Mortadella, Italian Mortadella, Mortadella Bologna and poultry meat Mortadella (chicken or turkey). Both Italian and Bologna are considered the noblest mortadellas and addition of mechanically deboned chicken meat (MDCM) or starch is not allowed in their formulation. For the products classified as Mortadella, Bologna-type Mortadella and poultry meat Mortadella the addition of both mechanically deboned chicken meat and starch is allowed and these products are popular and cheapest. In the case of chicken mortadella it is required that the raw material be chicken meat and the addition of up to 40 % mechanically deboned chicken meat and starch is accepted.

Mortadella is one of the leading products in the Brazilian market, with a consumption that reached 0.827 kg/per capita/year; the south of the country had the highest consumption (1.599 kg/per capita/year) (IBGE 2010). In Brazil, besides being a popular food, mortadella has high fat levels, which can reach 30 %, a level permitted by Brazilian legislation (MAPA 2000). Due to the growing interest in reducing sodium and fat levels, several studies are being published considering different formulations of this kind of meat product (Horita et al. 2011; Barbieri et al. 2013).

Within this context, the aim of the present study was to test the influence of different starches (native and modified) on the physicochemical, sensory, structural and microbiological characteristics of low-fat chicken mortadella.

Materials and methods

The experiments were performed in the laboratories of the Department of Food Science and Technology of the Federal University of Santa Maria (UFSM, Santa Maria RS, Brazil). The project was approved by the Ethics Committee of UFSM (CAAE: 1574213.8.0000.5346). Microscopy was performed in the histology laboratory of the Department of Pharmacy of the Integrated Regional University of Alto Uruguai e das Missões (URI, Erechim RS, Brazil). For the development of the mortadella, the formulations the Technical Regulation of Mortadella Identity and Quality (MAPA 2000), Ordinance No.1004 (ANVISA 1998) were followed. The addition of native starches respected the maximum allowed by Brazilian legislation (5 % w/w) and for the other starches the tested concentration was half of that (2.50 % w/w), aiming at cost reduction and seeking similar or better performance for the modified starches when compared with the native ones.

Two different native starches were tested, one of regular corn (*Zea mays* L.), bought from Nutract (Chapecó, SC, Brazil) and another of cassava (*Manihot esculenta* C.) from

the Fecularia São Miguel (São Miguel do Oeste, SC, Brazil). The modified starches that were considered in the present study were Thermtext[®] (hydroxypropyl distarch phosphate derived from waxy maize) and Novation 2300 (obtained from physically modified waxy maize starch), which were donated by the National Starch and Chemical Company (Trombudo Central, Santa Catarina, Brazil). The mortadella was prepared in a 5 kg capacity cutter (Visa, Brusque, SC, Brazil). The raw meat that was used was skinless chicken thighs and drumsticks from frozen chickens, and frozen mechanically deboned chicken meat, which were donated by the Aurora Central Food Cooperative (São Miguel do Oeste, SC, Brazil). The meat raw material was not trimmed or separated from fat, only the skin was removed. No lard was used due to the fact that the Brazilian law (MAPA 2000) does not allow addition of raw materials from other animals but chicken in this product. The base formulation (items that did not differ for all the formulations) consisted of the following ingredients and additives: frozen mechanically deboned chicken meat (30 %); ice (10 %), soy protein concentrate (4.%) (Solae, Esteio, RS, Brazil); salt (2.20 %) (Diana, São Paulo, SP, Brazil); sodium polyphosphate (0.50 %) (Kerry, São Paulo, SP, Brazil); dehydrated glucose (0.50 %) (Corn Products, São Paulo, SP, Brazil); acidity regulator (0.50 %) (Nutract, Chapecó, SC, Brazil); semi-refined kappa-carrageenan (0.50 %) (FMC, São Paulo, SP, Brazil); sodium erythorbate (0.10 %) (Wenda, São Paulo, SP, Brazil); monosodium glutamate (0.10 %) (Ajinomoto, São Paulo, SP, Brazil); sodium nitrite (0.015 %) (BASF, São Paulo, SP, Brazil); flavoring (0.015 %) (Kraki, São Paulo, SP, Brazil) and 3 % cochineal carmine (0.010 %) (CHR Hansen, São Paulo, SP, Brazil). The other ingredients that differed in percentages according to the experimental design are shown in Table 1.

The low-fat chicken mortadella preparation process consisted of grinding, mixing and emulsifying ingredients in a cutter as described by Forrest et al. (1979), Barbieri et al. (2013) and Horita et al. (2011). The order of mixing the ingredients and additives was: grinding the meat raw material

and the mechanically deboned chicken meat (2 min), addition of sodium polyphosphate (1 min), addition of water with dissolved colorant and addition of salt (2 min), addition of concentrated soybean protein (2 min), addition of dried glucose, acidity regulator, monosodium glutamate, flavorings, sodium nitrite (2 min) and, finally, carrageenan and sodium erythorbate (3 min). The process total time was of 12 min and the maximum final temperature was of 8 °C.

The pieces were embedded in artificial casings (five-layer bi-oriented nylon/poly with a thickness of 0.12 mm) and cooked in water until reaching an internal temperature of 75 °C. They were then cooled in a bath with cold water and ice (4 °C) until they reached 7 °C. The mortadella pieces were subsequently stored under refrigeration (7 °C) until analysis. The product was characterized by determining the water content (indirect gravimetric method at 105 °C), mineral residue (incineration method in a muffle at 550 °C), proteins (microKjeldahl method), lipids (Soxhlet), starch (Lane-Eynon) and pH (potentiometry) (AOAC 1990; IAL 2005). Water activity (a_w) was evaluated using Aqualab Lite[®] (Decagon Device LatAm, São José dos Campos, SP, Brazil) at 25 °C.

Freeze-thaw losses (FTL) were performed according to the methodology of Lee et al. (2002) with some modifications; the samples were cut into rectangles of approximately 1 cm in height and were divided into four parts. The samples were then weighed and packed individually in plastic containers (polyethylene) and taken to be frozen at −18 °C. After 24 h of freezing, the pieces were thawed at room temperature (20 °C) for 4 h and then packed in filter paper, which was 12.5 cm in diameter. The samples were then pressed between two glass plates under a mass of 2,000 g for 5 min. After pressing, they were removed from the filter paper and re-weighed; the percentage of water that was lost was determined by the difference in weight. For cooling loss (CL), the packed mortadella samples were stored and refrigerated for 7 days; they were individually weighed, before and after wiping the product and the packages with paper towels.

Table 1 Starches and raw material used for the development of chicken mortadella formulations with reduced fat

Tested starches / formulations	Concentration (%)	Raw material ^b (%)	
Native	Cassava starch ^a (CASS)	5.00	46.28
	Corn starch (CORN)	5.00	46.28
Modified	Modified starch 1 ^c (MOD1)	2.50	48.78
	Modified starch 2 ^d (MOD2)	2.50	48.78

^a Corresponds to standard sample

^b Corresponds to skinless chicken drumsticks and thighs. Values that differed between the formulations when smaller proportion of modified starch were used

^c Corresponds to Novation 2300

^d Corresponds to Thermtext[®]

Losses due to reheating (RL) were performed according to the methodology proposed by Hachmeister and Herald (1998) and the samples were cut into uniform sizes of $2.0 \times 2.0 \times 6.0$ cm and weighed. They were then immersed in about 300 mL of boiling water in a 500 mL beaker, covered with watch glass, and kept for 6 min. They were subsequently drained on a paper towel and refrigerated (5 °C) for 6 min. The percentage of loss due to reheating was given by the difference in weight.

Instrumental texture was evaluated by using a TA.XTplus texture analyzer (Stable Micro Systems, Godalming, UK), at 20 °C, with five repetitions; the results were collected using Texture Exponent Lite software (Stable Micro Systems). For the texture profile analysis (TPA) the samples were cut into 2 cm cubes and submitted twice to 80 % compression using a 75 mm cylindrical probe at constant speed (1.0 mm.s^{-1}), with an interval of 5 s between the first and the second compression. From the TPA curve the following parameters were evaluated: hardness (N), adhesiveness (N.mm), cohesiveness, elasticity (mm) and chewiness (N.mm) (Ramos and Gomide 2007).

Color was analyzed according to the system of the International Commission on Illumination (CIE), using the L^* , a^* and b^* coordinates (CIELAB scale) where L^* is brightness, a^* is intensity of red, and b^* is intensity of yellow. For this analysis, the axes of color (L^* , a^* and b^*) were determined using a colorimetric spectrophotometer, Minolta® CR-310 (Konica Minolta Sensing Americas Inc., Ramsey, New Jersey, USA) with D65A illuminant. Readings were carried out using slices of mortadella approximately 5 mm thick (5 °C). The colorimeter was calibrated and the readings were taken on the surface of the products. The C index (saturation) and H (hue) were also calculated by using Eqs. 1 and 2:

$$Cab = \sqrt{(a^*^2 + b^*^2)} \quad (1)$$

$$h = \tan^{-1} \left(b^* / a^* \right) \quad (2)$$

Microbiological analysis was performed according to the standards required by the ANVISA (2001) (coliforms at 45 °C/g, coagulase positive *Staphylococcus aureus*/g, sulphite reducing clostridia to 46 °C/g and *Salmonella* sp/25 g).

Sensory analysis was carried out using two tests: the multiple comparison test (comparison with the developed standard) and the preference test (Dutcosky 1996; IAL 2005). Multiple comparison tests were used to assess whether there was a difference between the standard sample (CASS) and the other tests (CORN, MOD1 and MOD2) in relation to texture. The principle of the test consisted in providing a slice of the standard sample, specified with the letter S, and other slices of

coded samples. The testers were asked to taste the samples and compare them with the standard across a scale (1=best, 2=equal, 3=worse). For the preference test, tasters chose the preferred sample when compared with the others. For both tests, the samples were offered as slices of 5 mm thickness. Seventy-four untrained testers participated in the evaluation and the experimental procedures were duly approved by the Federal University of Santa Maria (UFSM).

For microscopy, three fragments were removed from each treatment, corresponding to the center of the mortadella. The material was processed according to the conventional technique cited by Junqueira and Carneiro (2008). The samples were qualitatively evaluated for the presence of: muscle fibers, fat, fibrous and compact tissue, edema, starch, cytoplasmic vacuoles, disruption, disorganization and binding tissue. Three slides were prepared for each treatment. The samples were cut into sections with a thickness of 4 µm and then stained with hematoxylin and eosin. An optical microscope (Leica Microscopy Systems, Heerbrugg, Switzerland) was used, and Motic Images Plus 2.0. (Motic Instruments, Inc., Richmond, Canada) software was used to capture the images.

Three repetitions were performed for each experiment and the analyses were carried out in triplicate, at least. The results were submitted to analysis of variance (ANOVA) and Tukey's test with a significance level of 95 % ($p < 0.05$), using Statistica® 8.0 (StatSoft Inc., Tulsa, OK, USA) software.

Results and discussion

Table 2 shows significant difference ($p < 0.05$) for moisture, lipids and starch contents, a_w and pH; there was no difference ($p > 0.05$) for the levels of protein and mineral residue for the mortadella formulations.

Moisture ranged from 64 % (CORN) to 66.2 % (MOD1) and the highest values were found in the MOD1 and MOD2 formulations, which may have been due to the lower content of starch, when compared with the CASS and CORN formulations, which was reflected, as expected, in higher a_w values. Most studies report moisture increase in reduced fat meat products and this is related to high meat content, as well as the level of soluble solids in the formulation (Pietrasik and Janz 2010; Brewer 2012).

The experimental results for starch level ranged from 2.16 % (MOD2) to 4.32 % (CORN) and were in accordance with the added percentages of starch in the formulations. The small differences between added and detected starch were related to the limitations of the analytical method.

The levels of starch, protein and moisture that were found for the CASS, CORN and MOD2 samples were in accordance with the limits established by Brazilian legislation (maximum moisture of 65 %, minimum protein content of 12 % and maximum of 5 % starch) (MAPA 2000). The MOD1

Table 2 Results for moisture, protein, lipids, ash, starch contents, a_w and pH for the developed formulations of chicken mortadella with reduced fat (CASS, CORN, MOD1 and MOD2)

Formulations ^{a*}	Moisture* (%)	Protein* (%)	Lipids* (%)	Ash* (%)	Starch* (%)	a_w	pH
CASS	64.54 ^b ±0.11	15.55 ^a ±0.95	9.52 ^{ab} ±0.44	4.28 ^a ±0.10	4.04 ^b ±0.10	0.968 ^{ab} ±0.001	6.39 ^{ab} ±0.21
CORN	64.00 ^b ±0.91	16.46 ^a ±0.62	10.70 ^a ±0.97	4.44 ^a ±0.36	4.32 ^a ±0.01	0.965 ^b ±0.004	6.21 ^b ±0.14
MOD1	66.22 ^a ±0.17	16.27 ^a ±0.73	9.43 ^a ±0.31	4.19 ^a ±0.04	2.47 ^c ±0.01	0.969 ^a ±0.002	6.39 ^{ab} ±0.02
MOD2	65.10 ^b ±0.12	16.28 ^a ±0.35	9.63 ^{ab} ±0.19	4.18 ^a ±0.04	2.16 ^d ±0.01	0.969 ^a ±0.002	6.40 ^{ab} ±0.03

^a Means±standard deviation shown with different letters differ significantly in the columns ($p<0.05$). CASS=5% Native cassava starch; CORN=5% native corn starch; MOD1=2.5% Novation 2300. MOD2=2.5% Thermtext. *Expressed on a wet basis

formulation did not have the permitted moisture level. The formulations containing native starches (CASS and CORN) presented lower moisture values due to the use of a higher concentration of this polysaccharide but only the CORN sample also had an additional decrease in water activity, which contributes to the shelf-life of products. The variation in moisture level can also be justified by differences in the composition of the raw material, the percentage of raw material used, the degree of trimming, and also to the system of production of the animals (chickens).

Lipid contents ranged from 9.43 % (MOD1) to 10.70 % (CORN). With these results, all the formulations could be classified as “light” as they had a reduction of more than 25 %, when considering that Brazilian legislation establishes 30 % as the maximum lipid content for this product (ANVISA 2012). The lipid contents found were dependent of the fat level present on the employed raw materials (thighs and drumsticks and mechanically deboned chicken meat). The lipid content of the final product was low due to no addition of extra fat on the formulation that had only the lipids present on the chicken thighs and drumsticks as well as on the MDCM. As established by the Brazilian legislation, MDCM maximum fat content cannot be above 30 % whereas chicken thighs and drumsticks without skin have average of 5.74 % fat (Prestes et al. 2013). The values of pH and a_w varied from 6.21 (CORN) to 6.40 (MOD2) and 0.965 (CORN) to 0.969 (MOD1 and MOD2), respectively. The pH values were in accordance with those found by Pietrasik and Janz (2010), 6.30 to 6.63, and with the study by Chin et al. (1999), which reported 6.37 to 6.5 for reduced fat mortadella.

Liu et al. (2008) tested thermostable modified potato starch (2 or 4 %) as a fat replacer in sausages and noted fat reduction in relation to the standard, which had 30 % of lipids. Furlán et al. (2014) observed an increase in the average protein content (19.26 % until concentrations ≥ 20.28 %) and fat reduction (18.30 % to levels ≤ 13.79 %) in processed meat products with added inulin and bovine plasma as fat replacers.

The physical characteristics of the mortadella samples are presented in Table 3. Significant differences ($p<0.05$) were observed for color (L^* , a^* , b^* , C, H) and for losses (freeze-

thaw and reheating losses) and there was no difference ($p>0.05$) only for the parameter of cooling loss (CL). When considering the color parameter L^* , the values were between 60.42 (CASS) and 64.05 (CORN). The use of cassava starch resulted in a lower L^* value, whereas regular corn starch caused an increase in the L^* value. The a^* value varied from 15.29 (CORN) to 17.28 (CASS). The addition of cassava starch was associated with the greatest reduction in the a^* value, and regular corn starch was the formulation with the most altered value for this parameter.

The b^* value was highest for the CORN formulation (9.17) and CASS was the formulation with the lowest value (8.67), which means yellowing of the product for the formulation produced with regular corn starch. The variations in the a^* and b^* values was reflected in the C and h parameters.

The addition of polysaccharides is generally reported as resulting in a decrease in L^* and a^* parameters and an increase in the b^* parameter in meat products. In the present study, it was noted that cassava starch had the highest L^* reduction but, on the other hand, it caused the lowest influence on a^* and b^* values. Regular corn starch resulted in products with the worst values for a^* and b^* , i.e., increased yellowing and lower redness. Sweedman et al. (2013) mention that one of the advantages of some modified starches is that they are more soluble in water and they produce viscous transparent polymer solutions with low impact in the final product color.

A recently published paper (Zhang et al. 2013) showed that the addition of cassava starch (3, 6 or 9 %) resulted in increased L^* values and a reduction of a^* and b^* values in surimi. The authors explained that adding cassava starch resulted in changes in the gel transparency and that the alteration in the a^* value could have been related to myoglobin denaturation and gelatinization. They also mentioned that the swelling of the starch granules could have been related to alterations in the b^* value. Youssef and Barbut (2011b) reported an increase in L^* and b^* , and a reduction of a^* value when considering different fat replacers. Lightness (L^*) is related to the degree of clarity, indicating whether the colors are bright or dark. The light source is pointed at the sample and the response represents the proportion of reflected light.

Table 3 Results for L* (brightness), a* (green to red), b* (blue to yellow), C (Chroma), h (Hue), freeze-thaw loss (FTL), reheating loss (RL) and cooling loss (CL) for the the developed formulations of chicken mortadella with reduced fat (CASS, CORN, MOD1 and MOD2)

Formulations ^{a*}	L*	a*	b*	C	h	FTL (%)	RL (%)	CL (%)
CASS	60.42 ^d ±1.20	17.28 ^a ±0.65	8.67 ^{ab} ±0.58	19.35 ^d ±0.44	0.47 ^a ±0.04	0.02 ^b ±0.01	0.40 ^a ±0.07	0.16 ^a ±0.04
CORN	64.05 ^a ±1.35	15.29 ^c ±1.05	9.17 ^a ±0.43	17.84 ^{ab} ±0.82	0.54 ^a ±0.04	0.07 ^{ab} ±0.02	0.29 ^{ab} ±0.15	0.22 ^a ±0.12
MOD1	61.89 ^c ±0.67	16.43 ^{bc} ±0.27	8.75 ^{ab} ±0.31	18.61 ^c ±0.36	0.49 ^b ±0.01	0.08 ^a ±0.01	0.22 ^c ±0.06	0.25 ^a ±0.13
MOD2	62.61 ^{bc} ±0.78	16.20 ^b ±0.30	8.81 ^{ab} ±0.51	18.45 ^{bc} ±0.32	0.50 ^b ±0.03	0.02 ^b ±0.01	0.20 ^{bc} ±0.22	0.22 ^a ±0.15

^a Means±standard deviation shown with different letters differ significantly in the columns ($p<0.05$). CASS=5.00% native cassava starch. CORN=5.00% native corn starch. MOD1=2.50% Novation 2300. MOD2=2.5% Thermtext. *Expressed on a wet basis

Higher a* values indicate a redder color and lower values indicate a greener color; whereas, higher b* values indicate yellowness and lower b* values indicate a bluer color (Ramos and Gomide 2007). The a/b ratio is also useful to show the color changes from pink to a brown or brownish product. The interaction of myoglobin with starch causes a dilution in myoglobin and consequent changes in the absorption, leaving it near to 400 nm. The reduction in L* values and increased b* values result in a more opaque product. Lower L* values and higher b* values can be explained by the reduction in the concentration of myoglobin in meat (Youssef and Barbut 2011a).

The CASS and MOD2 formulations had the lowest values for freeze-thaw loss. When considering reheating loss, the samples produced with the addition of modified starches (MOD1 and MOD2) presented the lowest values. Zhang and Barbut (2005) tested different starches (potato, cassava and modified starch) in a meat product made with chicken breast meat and also concluded that the use of modified starch reduced cooking loss. Pedroso and Demiate (2008) also reported that using starch and carragenan in turkey cooked ham resulted in lower values for cooking and reheating losses, indicating the desirable increase in the water-binding capacity due to the addition of hydrocolloids in this class of food.

Reheating loss values were lower in the formulations produced with modified starches (MOD1 and MOD2), indicating the better stability of these products in stress conditions. The MOD2 formulation was the one that presented the highest water retention without important losses, representing the better performance of this starch inside the meat emulsion. The CASS formulation showed the highest reheating loss values (0.40 %). In the present study, the losses were lower than those reported by Zhang et al. (2013), who found values >1.0 % and close to the lowest values found by Youssef and Barbut (2011b). Modified corn starch evaluated by Moghaddam et al. (2013) also presented higher stability when compared to its native counterpart. Zhang et al. (2013) also

observed higher cooking losses for surimi containing 6 or 9 % of cassava starch. Sweedman et al. (2013) report that several types of modified starches present superior freeze-thawing stability due to chemical changes that prevent long chain realignment when the gel is stored under low temperatures.

Table 4 shows the results for texture evaluation and sensory analysis. There was significant difference ($p<0.05$) for hardness, adhesiveness, chewiness and in the multiple comparison test. There was no significant difference ($p>0.05$) for cohesiveness, elasticity, as well as in the preference test. The lowest hardness value (128.79 N) was found for the CASS sample and the highest (190.94 N) was for CORN.

Liu et al. (2008) tested thermostable modified potato starch (2 and 4 %) as a fat replacer in sausage (5 and 15 % reduction) and the sausages with 2 % of modified starch and 15 % of fat had similar hardness to the control, which contained 30 % fat. Youssef and Barbut (2011b) reported a decrease in a comminuted product with a reduction from 25 to 10 % of fat as well as an alteration in cohesiveness, depending on the level and type of the fat replacers that were tested.

The differences in hardness values resulted in different values of chewiness, as the latter is calculated from the hardness, adhesiveness and elasticity values of the product. The differences in texture was also perceived in the sensory evaluation, where tasters considered the CORN sample as being between equal and worse than the standard; the MOD2 formulation was considered to be between equal to and better than the standard.

The CORN formulation presented lower moisture, and consequently higher hardness. Despite presenting low moisture, the CASS formulation did not have a high hardness value. The CASS formulation was produced with the addition of 5.0 % of starch but presented lower hardness values, even when compared with the formulations made with 2.5 % of modified starches (MOD1 and MOD2).

Table 4 Results obtained for hardness, cohesiveness, adhesiveness, elasticity, chewiness and multiple comparison and preference test for the developed formulations of chicken mortadella with reduced fat (CASS, CORN, MOD1 and MOD2)

Formulations ^{a*}	Hardness (N)	Cohesiveness	Adhesiveness (N.mm)	Elasticity (mm)	Chewiness (N.mm)	Comparison ^b	Preference ^c
CSS	128.79 ^c ±3.44	0.73 ^a ±0.02	-0.50 ^a ±0.26	1.17 ^a ±0.06	128.99 ^b ±3.61	1.99 ^{ab} ±0.82	2.81 ^a ±1.53
MS	190.94 ^a ±11.01	0.74 ^a ±0.02	-0.25 ^{ab} ±0.07	1.22 ^a ±0.03	173.35 ^a ±9.90	2.14 ^a ±0.82	2.81 ^a ±1.37
NV	146.96 ^b ±3.65	0.72 ^a ±0.01	-0.18 ^{ab} ±0.01	1.17 ^a ±0.08	123.35 ^b ±5.70	2.04 ^{ab} ±0.78	2.83 ^a ±1.33
TM	142.59 ^b ±4.41	0.71 ^a ±0.01	-0.41 ^{ab} ±0.24	1.23 ^a ±0.04	123.96 ^b ±8.35	1.76 ^b ±0.77	3.35 ^a ±1.40

^a Means±standard deviation shown with different letters differ significantly in the columns ($p<0.05$). CASS=5.00% native cassava starch. CORN=5.00% native corn starch. MOD1=2.50% Novation 2300. MOD2=2.5% Thermtext. *Expressed on a wet basis

^b Evaluation criteria for comparison: 1=best-1, 2=equal, 3=worse than the standard regarding texture

^c Criteria used for preference: 5=most preferred and 1=less preferred

Rolland-Sabaté et al. (2012) explain that regular corn starch has around 28.7 % of amylose, whereas cassava starch has between 16.8 and 19.0 % of this linear polysaccharide. Starches that are richer in amylose present higher gel strength due to long linear chains of the polymers, which dissolve in solution and which, during heating, become linked by hydrogen bonds to the meat gel matrix resulting in texture changes in the products. During storage, amylose molecules tend to re-associate, with concomitant liquid release from the gel in phenomena known as retrogradation and syneresis. These dynamics influence the liquid losses of meat products during storage. Amylopectin molecules, on the other hand, do not release as much liquid from the structure of the weak gel (Petracci et al. 2013; Rolland-Sabaté et al. 2012).

The CORN formulation had the highest value for hardness and consequently for chewiness. Small differences in texture were also noted in the sensory test for the CORN sample, with the worst score, being ranked as equal or worse than the standard (CASS). In the preference test, there was no sample considered more or less preferred by the tasters, although the MOD2 formulation received the highest score (3.35). This result is interesting as the use of native or modified starches did not affect the preference among the formulations and the MOD2 formulation presented some results for TPA analysis that were close to those of the formulation considered as standard (CASS).

Prestes et al. (2012) employed Firm Tex[®] modified starch to produce cooked turkey ham without the addition of isolate soy protein. The best results reported by these authors regarding physical and sensory analyses, were for a formulation produced with 2 % of that starch. Despite modified starches being more expensive, technological advantages such as reduction of losses and better quality must be considered when choosing the right ingredients/additives for developing meat products.

In the microbiological evaluation, all the samples were in accordance with the standards established by Brazilian legislation (ANVISA 2001) (results not shown). When sensory analysis is considered, the MOD2 formulation was the one that presented the best performance in the multiple comparison test (lowest value) and in the preference test (highest value) with average scores of 1.75 and 3.35 respectively.

Figure 1 shows the microphotographs (A to H) taken by the hematoxylin and eosin methods for the different formulations. Light microscopy was employed with the objective of evaluating the relationship between the physical properties of the food system with the microscopic structural characteristics. The microscopic examination of the samples made it possible to study the muscular fibers, adipose tissue, connective tissue, edema, cytoplasmic vacuoles, presence of the distinct starches, disruption, disorganization and tissue binding.

It was possible to observe that the addition of different starches (native vs. modified) affected the structure of the product. The A, B, G and H photomicrographs show a structure that is more cohesive and with a more compressed matrix when compared with the photomicrographs C, D, E and F, probably due to the better distribution and interaction of the cassava starch and the modified starch (MOD2), which filled the protein matrix and resulted in a homogenous emulsion. The MOD1 formulation corresponds to the photomicrographs E and F, which show a lower structural organization and worse starch distribution in the emulsion structure. Weiss et al. (2010) state that modified starches have been tested as fat replacers with a view to improving water retention and gel properties in meat products. In the present study, the microscopic analysis showed that the starch granules were similar to adipocytes (fat cells) and

Fig. 1 Photomicrographs of the reduced-fat chicken meat mortadella formulations showing a detail in the right side of **a** and **b** - Formulation CASS. Please note muscle cell disruption (arrows) aside dispersed adipose and connective tissues (*). **c** and **d** Formulation CORN shows organized muscle tissue with a normal aspect (arrows) aside adipose and connective tissues (*). **e** and **f** Formulation MOD1 presents intense disorganization of the muscle tissue (arrows) aside apparently normal adipose cells (*). **g** and **h** Formulation MOD2 shows the presence of adipose tissue (*) and muscle cells with a light cytoplasmatic disruption (arrows). Hematoxylin and Eosin. Amplifications of 40× and 100× respectively

proved the visual effect of the different starches tested as fat replacers.

Song et al. (2010) reported that sausages made with the addition of native waxy corn starch presented higher porosity and more irregular pores when compared with the same sausage made with the addition of modified waxy corn starch. In this last case, the structure was more compact and the texture was superior. In our study, a similar behavior can be seen by comparing the adhesiveness shown in photomicrographs C and D (native regular corn starch) with E, F, G and H (modified corn starches: MOD1 and MOD2).

By comparing the microscopic observations with the results of texture and losses evaluation, it is possible to conclude that there is a relationship between some of these properties. CASS and MOD2 had the best starch distribution and the most organized structure, which was reflected in lower hardness or higher softness of the product. Despite the fact that the structure seemed more organized, the starch type influenced the losses, and higher reheating losses were found for CASS when compared with MOD2, which may have been related to the way the starch interacted within the product matrix.

The best global results were found for the MOD2 formulation, indicating that this modified starch resulted in similar texture if compared with the standard formulation (CASS), had lower reheating losses, and also had better results for sensory evaluation. In the case of the CORN

formulation, despite having a cohesive structure, excessive hardness had a negative effect on the preference of the product.

Conclusion

The use of native and modified starches significantly affected ($p < 0.05$) the physicochemical, sensory and structural characteristics of reduced fat chicken meat mortadella. The formulations produced with native cassava or corn starches (CASS and CORN, respectively) and with one type of modified starch (MOD2) were in accordance with Brazilian legislation in relation to a reduction in fat of at least 25 %, maximum moisture of 65 %, maximum starch content of 5 % and at least 12 % of protein.

The addition of 2.5 % modified starch to the formulations gave better results than the formulation made with 5 % native cassava starch, suggesting that the use of this type of starch is promising for developing high quality low-fat meat products. The addition of modified starch showed a better performance than the native starch in relation to the various evaluated technological parameters, mainly in relation to reheating losses, which demonstrated the good interaction between the modified starch in the structure of the product and the possibility of using this type of starch in other types of functional meat products.

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