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Effect of the addition of wheat fiber and partial pork back fat on the chemical composition, texture and sensory property of low-fat bologna sausage containing inulin and oat fiber

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Abstract

The objective of this work was to study the effect of adding wheat fiber and partial pork back fat on the quality characteristics of bologna sausage. The compound central rotating design was used with treatments containing fixed levels of inulin (5%) and oat fiber (1%) and variable levels of wheat fiber (0-4%) and pork back fat (0-10%). The pH and protein were similar in all the treatments, the fat was lower than the control treatment and the moisture content was higher than the control treatment (CF) without fibers. The wheat fiber increased the hardness and reduced cohesiveness and scores were given for overall impression. We found that it was possible to prepare low-fat bologna sausage with the addition of 6.58% fiber (5% inulin, 1% oat fiber and 0.58% wheat fiber), whilst retaining good sensory acceptability, thus reducing the pork back fat levels by between 25 and 42.75%.

Keywords: fat substitutes; wheat fiber; bologna sausage; microstructure.

Practical Applications: Bologna sausage was developed with 6,58% added fibers and partial fat with good sensory acceptability.

1 Introduction

Meat and meat products occupy a prominent position in the human diet because of their high quality protein content, essential amino acids and good source of B-group vitamins, minerals and other ingredients. However, many consumers believe the consumption of meat and meat products is unhealthy because of their high animal fat, cholesterol and other ingredients (Hygreeva et al., 2014). The strategies for reducing the fat content in meat products follow two basic principles: the use of lean cuts that can increase the costs and/or the reduction of fat by the addition of water and other ingredients (Jiménez-Colmenero, 1996).

Due to their functional and technological properties, dietary fibers have been considered as a replacement for fat in several applications in the meat industry (Hughes et al., 1997; Cofrades et al., 2008; Cava et al., 2012; Ktari et al., 2014; Schmiele et al., 2015). The consumption of fiber has been recommended due to the health-beneficial physiological attributes, including the reduction in intestinal transit time, prevention of constipation and reduction of the risk of such chronic diseases such as cancer, Type 2 diabetes (through the reduction of the intestinal absorption of glucose) and cardiovascular diseases (through hypocholesterolemic effects and the control of obesity) (Sánchez-Alonso et al., 2007b; Borderías et al., 2005; Mendoza et al., 2001; Choi et al., 2014; Talukder, 2015).

From a technological viewpoint, the inclusion of soluble and insoluble fiber has mainly been done in restructured and

emulsified products (Ayo et al., 2007; Fernández-Ginés et al., 2004; Turhan et al., 2005; Ktari et al., 2014) due to the excellent capacity of these products in retaining water and fat, a neutral odor, an improvement in the slicing of the products, hardness and the reduction in formulation costs. Despite these favorable properties, the substitution of fat through the addition of fiber is a great challenge in the development of meat products with regard to the preservation of palatability and shelf life. Fat contributes to the global acceptance of a meat product because it modifies the perception of flavor when influencing the release, intensity, migration and distribution of the compounds responsible for this attribute (Akoh, 1998). The partial substitution of animal fat by the addition of water and fiber can result in the release of liquids in the package during storage with a concomitant loss in hardness (Carballo et al., 1996; Claus et al., 1990). Cengiz & Gokoglu (2005), Mansour & Khalil (1999) and Keeton (1994), related that reformulation with fat substitutes can cause a decrease of the emulsion particle size, a darkening of the product, a loss of flavor and, subsequently, in palatability and a decrease in the shelf life from a microbiological point of view. Scanning electron microscopy was used to evaluate differences in meat emulsion structure and to compare them.

Bologna sausage is one of the main cooked emulsified meat products manufactured in Brazil and is appreciated in many countries. Its fat content usually varies between 20 and 30%, which has motivated consumers to limit their purchases of this

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product. Several studies have reported on the use of insoluble and soluble fiber in emulsified products (Sánchez-Alonso et al., 2006, 2007a; Brooks et al., 2006; Piñero et al., 2008; Mansour & Khalil, 1999; Steenblock et al., 2001; Warner & Inglett, 1997; Cava et al., 2012; Yang et al., 2007), highlighting their technological and prebiotic properties. The objective of this study was to determine the effect of the addition of wheat fiber and partial pork back fat in the chemical composition, texture and sensory properties of low-fat bologna sausage which already contains some fiber (5% inulin and 1% oat fiber).

2 Materials and methods

2.1 Materials

Lean beef (70.10% moisture content and 5.95% fat content) and pork back fat (19.32% moisture content and 78.76% fat content) were obtained from the local slaughterhouse with appropriate quality assurance. All of the subcutaneous, intramuscular fat and visible connective tissue from the lean meat and pork back fat were removed and the resulting products were minced through a 5mm and 8mm plate, respectively. The raw materials were then placed in polythene bags, vacuum sealed (Selovac CV60, 70 cmHg) and stored at -18°C until required, for a maximum of 12-18 h. The following non-meat ingredients were used: wheat fiber Vitacel WF200 (JRS & Söhne Inc., São Paulo, Brazil), with a minimum content of 94% dietary fiber, oat fiber Vitacel HF600 (JRS & Söhne Inc., São Paulo, Brazil), with 93% insoluble fiber and a maximum content of 3% soluble fiber, and soluble dietary fiber, Raftiline HPX (Clariant, São Paulo, Brazil) and inulin with high performance and extracted from chicory, composed of a mixture of fructose polymers, with a polymerization degree ranging from 2 to 60. The condiments and additives described in the formulation were provided by Kienast & Kratschmer Ltda (São Paulo, Brazil).

2.2 Experimental design

A complete factorial design was used to assess the influence of wheat fiber and partial addition of pork back fat on the technological and sensory properties of the cooked emulsified meat product (bologna sausage). Therefore, the independent variables and their variation levels were the wheat fiber, WF 200 Vitacel (0-4%), and pork back fat (0-10%). The experimental design resulted in 12 treatments (4 factorial, 4 central and 4 axial) and a control treatment, with the addition of 20% pork back fat but without the addition of fibers, for a total of 13 treatments. The composition of the batter mixtures is shown in Table 1; the encoded and real levels are shown in Table 2. The dependent variables were: hardness, cohesiveness and overall impression. In this study, 10% pork back fat, 1% oat fiber and 5% inulin were used in the 12 treatments prepared, based on the sensory properties of the bologna sausage with reduced fat content amended with fiber as reported in a previous study (Barretto & Pollonio, 2009).

Statistical Analysis System Institute (1999) was used to assess the results of the factorial design, to visualize the graphics of the response surface and analyze the effects was used to perform

ANOVA. The data were fitted to a second order equation (Equation 1) as a function of the dependent variables, as follows:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{12}X_1X_2 + b_{11}X_1^2 + b_{22}X_2^2 \quad (1)$$

where b_n represents the constant regression coefficients, Y represents the dependent variable and X_1 and X_2 are the coded independent variables.

2.3 Meat emulsion manufacturing

Following the compositions shown in Table 1, to process the mixture, the lean beef plus salt and half of the ice was added to the cutter (Incomaf, Brazil) and comminuted for extraction of the myofibrillar proteins.

The additives, the non-meat ingredients and the remaining ice were added to the cutter, which was in continuous operation at low speed. When the temperature reached 6-7°C, the fiber and pork back fat were added, again according to Table 1. The final temperature of the batter was standardized to a maximum of 18 °C. The mixture was then stuffed into a polyamide plastic casing, accommodating approximately 1 kg of the product. The resulting product was cooked in steam ovens until the internal temperature was 72 °C, and then cooled in running water for 30 minutes. The samples were stored under refrigeration until the time of analysis.

2.4. Chemical analysis (protein, fat, moisture and pH measurement)

The moisture and protein content of the low-fat bologna sausage were determined according to the methodology described by the Association of Official Analytical Chemists (1995). The fat content was quantified by the method described by Bligh & Dyer (1959). The pH value was measured using an MA 130 Mettler pH meter with a penetration probe, in corresponding segments of each newly processed formulation. All of the measurements were performed in quadruplicate.

2.5. Texture profile analysis (TPA)

The influence of the addition of the wheat fiber and the partial addition of fat on the texture was analyzed using a TA xT2i texture analyzer (Texture Technologies Corp., Scarsdale, NY) within ten days of production. All of the samples were compressed to 30% of their original weight. Three slices of 20 mm thickness were used to obtain six bologna sausage rolls with 20 mm diameters and 20 mm lengths, and a P-35 probe was used (long shaft, normal basis). The results were obtained after the samples reached the ambient temperature.

The following parameters were determined: hardness (N), the maximum force required to compress the sample; springiness (cm), the ability of the sample to recover its original form after the deforming force was removed; cohesiveness, the extent to which the sample could be deformed prior to rupture ($A2/A1$, where $A1$ is the total energy required for the first compression and $A2$ is the total energy required for the second compression); chewiness (N/cm), and the work required to masticate the sample for swallowing (Mendoza et al., 2001).

Table 1. The basic treatments of the bologna sausage in the full factorial design.

Ingredients	Treatments (%)									
	F1	F2	F3	F4	F5, F6, F7, F8	F9	F10	F11	F12	CF
Lean beef meat	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Pork back fat	1.45	1.45	8.55	8.55	5.0	5.0	5.0	0.0	10.0	20.0
Ice/Water	23.67	20.83	16.57	13.73	18.7	20.7	16.7	23.7	13.7	11.7
Cassava starch	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Mix bologna sausage Kraki	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Sodium nitrite	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Sodium tripolyphosphate	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Salt	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Sodium eritorbate	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Inulin - Raftiline	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	-
Wheat fibre Vitacel	0.58	3.42	0.58	3.42	2.0	0.0	4.0	2.0	2.0	-
Oat fibre Vitacel	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-

Table 2. Independent variable values and variance levels of the full factorial design.

Independent variables	Levels				
	- α (-1.41)	-1	0	1	+ α (+1.41)
X1 = Wheat fibre WF200 Vitacel (%)	0.00	0.58	2.00	3.42	4.00
X2 = Pork back fat (%)	0.00	1.45	5.00	8.55	10.00

2.6 Sensory evaluation

The acceptability test was used to assess the degree of how much the consumers liked or did not like the mentioned products with regard to overall impression. The panel consisted of 30 non-trained tasters, all consumers of meat products and all students of the State University of Campinas, SP, Brazil, and who were initially familiarized with the terminology adopted. The panelists were instructed to cleanse their palates with water between the samples. All the samples were presented to the potential consumers in a monadic sequential way, using a nine-point hedonic scale (1 = extremely disliked and 9 = extremely liked), in complete blocks divided into four sessions, as proposed by Macfie et al. (1989).

2.7 Scanning electron microscopy

Microscopic examination of the bologna sausage samples was performed, as described by Feng et al. (2003), with samples obtained by cutting ($2 \times 2 \times 7$ mm³) from the interior of the bologna sausage and fixed for 24h at 4°C in a 0.1 M phosphate buffer (pH 7) containing 2.5% glutaraldehyde. Fixed samples were dipped in the 0.1 M phosphate buffer (pH 7) for 10 min and then post-fixed for 5 h in 0.1 M phosphate buffer (pH 7) containing 1% osmium tetroxide. The fixed samples were washed three times, each time with 0.1 M phosphate buffer (pH 7) for 10 min, and dehydrated in an ethanol series (30, 50, 70, 95, and 100% for 30 min each). The samples were further dehydrated

by being submerged in absolute ethanol and then dried in warm air. The dried samples were mounted on copper sample holders, coated with gold (Sputter Coater SCD-050, Balzers), and examined under a Jeol – JSM – 5800 LV Scanning Microscope (Japan) with a 10 kV accelerating voltage.

3. Results and discussion

3.1 Moisture, protein, fat and pH

The results obtained for the moisture, fat, protein and pH are shown in Table 3. The formulations presented protein contents nearing 12%, as the only protein source was the meat. The results of the fat contents varied between the formulations and were related to the content added in the formulation. Talukder (2015) related that the addition of fibers can cause change in the pH of meat products. The addition of the fiber and pork back fat did not affect the pH values, which remained very similar between the treatments.

The moisture content of treatments was greater than the control treatment (CF) without fibers ($P < 0.05$). The moisture contents correlated with the quantity of water added in the different formulations, according to Table 1. In the treatments, when fibers were added, the fat was reduced and the water increased, but the quantity of meat was the same in all the treatments. Similar results were reported by Choi et al. (2009) and Schmiele et al. (2015), where the moisture content of meat emulsions were lower in those formulations with a greater addition of fat. Troy et al. (1999) and Mansour & Khalil (1999) also report that formulations of beef burgers with the addition of fat substitutes had contained more moisture when compared with control samples.

3.2 Analysis of the texture profile

Some studies have shown that products with a lower fat content are firmer and can compromise the overall sensory quality according to the rheological properties of the substitute ingredients used (Keeton, 1994; Choi et al., 2009; García et al., 2002). It was observed in this study that the greater the quantity of added wheat fiber, the greater the hardness. The results of the

Table 3. Results of the full factorial design for the moisture, fat, protein and pH.

Treatment	Wheat fibre % (X1) ^k	Pork back fat % (X2) ^k	Moisture (%)	Fat (%)	Protein (%)	pH 0 day
F1	0.58 (-1)	1.45 (-1)	67.33 ^a	5.07 ^h	12.32 ^{c,d,e,f}	6.08 ^c
F2	3.42 (+1)	1.45 (-1)	64.16 ^d	6.49 ^g	12.23 ^{d,e,f}	6.20 ^a
F3	0.58 (-1)	8.55 (+1)	62.40 ^f	8.65 ^{c,d}	11.84 ^g	6.20 ^a
F4	3.42 (+1)	8.55 (+1)	57.08 ⁱ	8.23 ^{d,e}	12.39 ^{c,d,e}	6.20 ^{a,b}
F5	2 (0)	5 (0)	62.31 ^f	8.23 ^{d,e}	12.89 ^{a,b}	6.20 ^a
F6	2 (0)	5 (0)	63.85 ^e	8.38 ^{c,d,e}	12.99 ^a	6.21 ^a
F7	2 (0)	5 (0)	64.56 ^c	8.78 ^c	13.07 ^a	6.25 ^a
F8	2 (0)	5 (0)	59.85 ^h	8.53 ^{c,d,e}	12.47 ^{c,d}	6.22 ^a
F9	0 (-1.41)	5 (0)	64.98 ^b	7.75 ^f	12.03 ^{f,g}	6.25 ^a
F10	4 (+1.41)	5 (0)	61.48 ^g	8.17 ^{e,f}	11.78 ^g	6.21 ^b
F11	2 (0)	0 (-1.41)	63.96 ^{d,e}	4.69 ^h	12.57 ^{b,c}	6.24 ^b
F12	2 (0)	10 (+1.41)	57.13 ⁱ	11.40 ^b	12.11 ^{e,f,g}	6.21 ^a
CF	-	-	55.74 ^j	13.85 ^a	12.41 ^{c,d,e}	6.21 ^{a,b}

^{a,h,c,d,e,f,g,h,i,j} Values with different letters within a row indicate statistically significant differences ($P < 0.05$). ^k Independent variable values (the values between brackets are the coded variables).

texture profile analysis are shown in Table 4. Only the linear effect of the variable wheat fiber was found to be significant ($p < 0.05$). The pork back fat did not have any effect on the hardness of the studied levels (0-10%), and the model obtained is as follows (Equation 2):

$$\text{Hardness} = 34.4852 + 8.6804 \cdot x_1 \quad (R^2 = 0.7925) \quad (2)$$

The response surface for hardness with regard to the wheat fiber and pork back fat is shown in Figure 1a. The control formulation (with the addition of 20% pork back fat) obtained a lower value for hardness than those obtained with the design. These results are in accordance with those found by Cofrades et al. (2008), in which the different effects found for three different types of edible seaweeds on the properties of meat texture emulsions corresponded to the different proportions and compositions of the dietary fiber used. These authors also report that insoluble fiber can increase the consistency of meat products by forming an insoluble three-dimensional network that is capable of modifying the rheological property of the continuous emulsion stage.

Regarding the springiness, it was not possible to establish a mathematical model regarding the studied variables because no effect was significant ($p > 0.05$). The analysis of variance was low ($R^2 = 0.7011$), and the $F_{\text{calculated}}$ (2.81) was lower than the $F_{\text{tabulated}}$ (4.39), so the values were not presented.

The cohesiveness was significantly lower in the samples with added fiber and a partial pork back fat reduction, as compared with the CF treatment, similar to the results of Choi et al. (2014) and Ktari et al. (2014), showing that the fat increased the cohesiveness when no fibers were added. Only the F1 treatment provided a result similar to the control formulation, when only 0.58% wheat fiber was added. The wheat fiber contributed significantly ($p < 0.05$) to the decrease of the cohesiveness. Figure 1b provides the response surface for cohesiveness according to

the wheat fiber and fat content. The model for this data is the following (Equation 3):

$$\text{Cohesiveness} = 0.7820 - 0.0331 \cdot x_1 \quad (R^2 = 0.8409) \quad (3)$$

The cohesiveness was decreased as the quantity of wheat fiber and pork back fat was increased. Mendoza et al. (2001) reported that the cohesiveness decreased with a reduction of the fat content.

The chewiness parameter was lower in the CF treatment. Similar results were found by Mendoza et al. (2001) and García et al. (2002), where the fiber significantly affected the chewiness of low-fat sausages. These results are expected because chewiness is the work required to masticate the sample for swallowing, and it is raised when fibers are added. It was not possible to establish a model in this study, because no effect was significant ($p > 0.05$) and the coefficient of determination was low ($R^2 = 0.6893$), so the values were not presented.

3.3 Sensory analysis

The results of the sensory analysis (overall impression) are presented in Table 4. The wheat fiber contributed significantly ($p < 0.10$) to the decrease of the scores given for overall impression and the model obtained was the following (Equation 4):

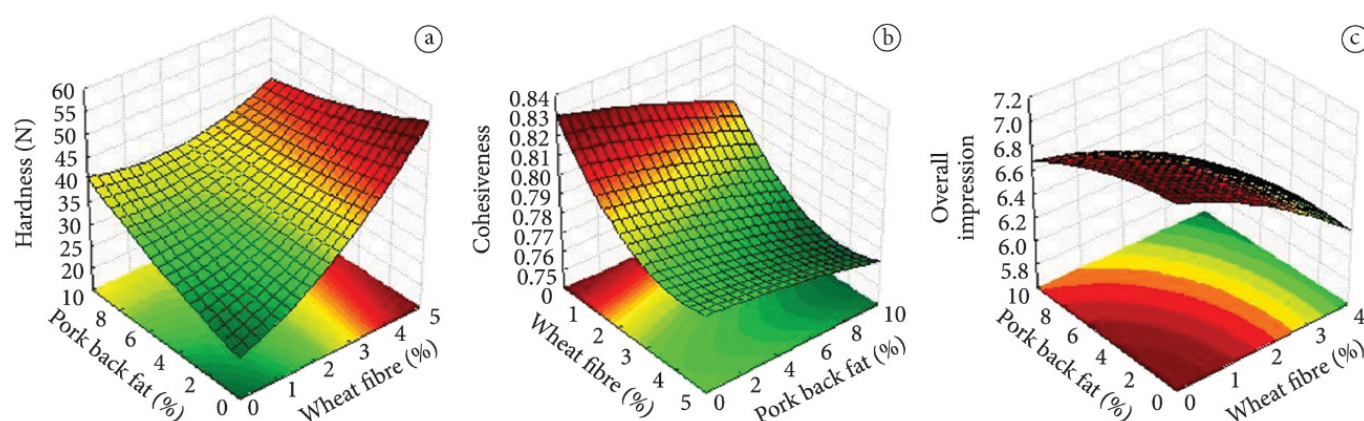
$$\text{Overall impression} = 6.6923 - 0.5368 \cdot x_1 \quad (R^2 = 0.7294) \quad (4)$$

The coefficient of determination was satisfactory, showing that the wheat fiber must be used in small quantities as a substitute ingredient for fat, as its use implies a decrease in overall impression scores in emulsified products, such as bologna sausage, with 6% fiber previously added (5% inulin and 1% oat fiber). And the partial addition of pork back fat in the studied levels (0-10%) did not contribute to global impression scores. The addition of 4% of wheat fiber (F10) was significantly different from the CF treatment. The response surface for the overall

Table 4. Results of the full factorial design for the TPA and sensorial analyses (scores).

Treatment	Wheat fibre % (X1) ^j	Pork back fat % (X2) ^j	Hardness (N/cm ²)	Cohesiveness	Overall impression
F1	0.58 (-1)	1.45 (-1)	27.53 ^{f,g}	0.8228 ^{a,b}	7.03 ^{a,b}
F2	3.42 (+1)	1.45 (-1)	42.09 ^{a,b}	0.7815 ^{e,f,g,h}	6.60 ^{a,b}
F3	0.58 (-1)	8.55 (+1)	34.60 ^{c,d,e}	0.8019 ^{c,d}	6.60 ^{a,b}
F4	3.42 (+1)	8.55 (+1)	38.24 ^{b,c,d}	0.7660 ^{h,i}	6.3 ^{a,b}
F5	2 (0)	5 (0)	32.84 ^{d,e,f}	0.7886 ^{d,e}	6.73 ^{a,b}
F6	2 (0)	5 (0)	39.57 ^{a,b,c}	0.7831 ^{e,f,g,h}	6.87 ^{a,b}
F7	2 (0)	5 (0)	34.29 ^{c,d,e}	0.7866 ^{d,e,f}	6.37 ^{a,b}
F8	2 (0)	5 (0)	31.21 ^{e,f}	0.7699 ^{f,g,h,i}	6.80 ^{a,b}
F9	0 (-1,41)	5 (0)	32.32 ^{e,f}	0.8071 ^{b,c}	7.07 ^a
F10	4 (+1,41)	5 (0)	43.95 ^a	0.7683 ^{g,h,i}	6.07 ^b
F11	2 (0)	0 (-1,41)	32.19 ^{e,f}	0.7853 ^{d,e,f,g}	6.63 ^{a,b}
F12	2 (0)	10 (+1,41)	41.59 ^{a,b}	0.7624 ⁱ	6.53 ^{a,b}
CF	-	-	23.73 ^g	0.8268 ^a	7.20 ^a

^{a,h,c,d,e,f,g,h,i} Values with different letters within a row indicate statistically significant differences ($P < 0.05$). ^j Independent variables values (the values between brackets are the coded variables).

**Figure 1.** Response surfaces of the effects of wheat fibre and pork back fat on a) hardness, b) cohesiveness and c) overall impression.

impression due to the wheat fiber and pork back fat is shown in Figure 1c. The addition of 6.58% fiber (5% inulin, 1% oat fiber both previously added and 0.58% wheat fiber) and 11.45% pork back fat (10% previously added pork back fat + 1.45% as shown in Table 4 for F1) did not differ from the CF treatment, without the addition of fiber and with addition of 20% pork back fat.

Andrés et al. (2006) observed that a low bovine fat content (0, 2 and 5%) did not affect the scores given for flavor, texture and global acceptance of low-fat chicken sausages. Troy et al. (1999) studied the effect of various mixtures on low-fat beef burgers and concluded that the flavor and texture are important attributes for acceptability and that no difference was found for the flavor in the studied mixtures.

3.4 Scanning electron microscopy

The bologna sausage formulations with higher scores (F1 and F9) for the overall impression and the CF treatment were prepared and subjected to scanning electron microscopy to assess the qualitative differences on the microstructure of the

emulsions formed. Figure 2 shows the microstructures of these treatments (CF, F1 and F9).

The CF treatment was characterized as homogenous and there was a greater presence of fat globules (Figure 2-CF). A good uniformity in the fat globules was observed for F1, though with an uneven size (Figure 2-F1). Andrés et al. (2006) also found different sizes of fat globules in low-fat chicken sausages. Totosa & Pérez-Chabela (2009) found similar reports, additionally mentioning the greater presence of pores, as characterized by the higher water content in low-fat formulations. The presence of insoluble fiber (wheat and/or oat) is notable in Figures 2-F1 and F9 with the presence fiber bundles that are not observed in Figure 2-CF. It is likely that the soluble fiber was dispersed in the matrix and could not be identified in the microstructure. The presence of insoluble fiber throughout the fat globule perimeter indicates the participation of the stabilization of the interfacial film that wrapped the fat (Figures 2a and b). These results may help to uncover the mechanism of meat emulsion formation in the presence of fiber and its behavior in the meat matrix.

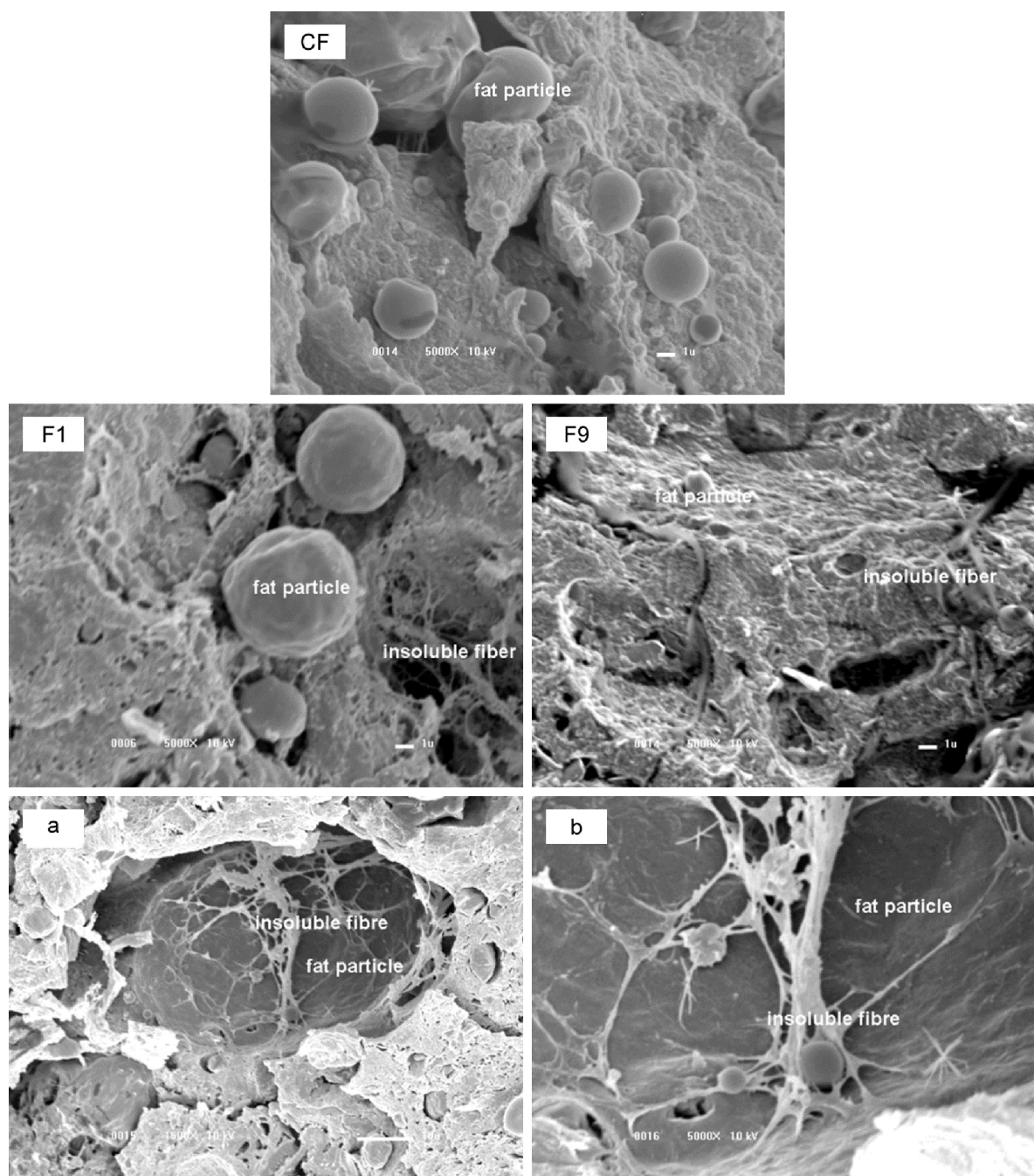


Figure 2. Scanning electron micrographs (magnification: 5000X) of bologna sausage with different treatments. CF = control (no added fiber), F1 = 0.58% wheat fiber and 1.45% pork back fat added, F9 = 0% wheat fiber and 5g/100g pork back fat. a, b = F9 with 1500X and 5000X magnification (same figure).

4 Conclusions

The technological identity pattern of the bologna sausage was preserved with the substitution of 25% to 42.75% added pork back fat and with the addition of 0.58% wheat fiber (with the previous addition of 1% oat fiber and 5% inulin). The wheat fiber contributed to increase hardness and decreases in both cohesiveness and in scores given for the overall impression. By using scanning electron microscopy, it was possible to visualize

the participation of the insoluble fiber in the formation of the interfacial film that wrapped the fat.

The bologna sausage with total addition of 6.58% fiber (1% oat fiber, 5% inulin and 0.58% wheat fiber) and 11.45% pork back fat (10% addition of fixed plus the 1.45% addition in the treatment) produced scores for overall impression, hardness and cohesiveness similar to the control bologna sausage (CF treatment) with the 20% pork back fat addition and without

the addition of fiber, showing the fibers can partially substitute fat in low-fat bologna sausage.

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