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Effects of pineapple byproduct and canola oil as fat replacers on physicochemical and sensory qualities of low-fat beef burger

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ABSTRACT

Pineapple byproduct and canola oil were evaluated as fat replacers on physicochemical and sensory characteristics of low-fat burgers. Five treatments were performed: conventional (CN, 20% fat) and four low-fat formulations (10% fat): control (CT), pineapple byproduct (PA), canola oil (CO), pineapple byproduct and canola oil (PC). Higher water and fat retention and lower cooking loss and diameter reduction were found in burgers with byproduct addition. In raw burgers, byproduct incorporation reduced L*, a*, and C* values, but these alterations were masked after cooking, leading to products similar to CN. Low-fat treatments were harder, chewier, and more cohesive than full-fat burgers. However, in Warner Bratzler shear measurements, PA and PC were as tender as CN. In QDA, no difference was found between CN and PC. Pineapple byproducts along with canola oil are promising fat replacers in beef burgers. In order to increase the feasibility of use of pineapple byproduct in the meat industry, alternative processes of byproduct preparation should be evaluated in future studies.

1. Introduction

Diets high in fats provide large amounts of saturated fat and cholesterol, which are associated with several chronic diseases. Due to this, changes in population's diet have been observed, with an increase in preference for low-fat products. Although meat cuts have become leaner, the same cannot be said about meat products, which still have high levels of fat (<10 up to 50%) (Jiménez-Colmenero, 2000). Burgers are frequently eaten products, mainly due to the current increase in the number of fast foods and because they are easy and fast to prepare (Rodríguez-Carpena, Morcuende, & Estévez, 2012). Thus, due to its high fat content and popularity, beef burger is an attractive choice for fat reduction.

Fat presents an important role in meat products, affecting sensory (juiciness, texture and flavor) (Jiménez-Colmenero, 2000) and technological aspects (cooking loss, emulsion stability, water holding capacity, rheological properties) (Hughes, Cofrades, & Troy, 1997). Considering these aspects, the simple fat reduction raises a number of technological problems and leads to a decline in palatability, resulting in less accepted products (Jiménez-Colmenero, 2000). Due to this, studies have been performed to reduce the fat amount of burger and maintain its quality through the incorporation of non-meat ingredients. Some of these ingredients are fibers and vegetable oils.

Fiber is one of the most common functional ingredients used in food products (Sánchez-Zapata et al., 2010). Its importance in the food market is related to the wide range of properties, which go from physiological effects to technological properties. The insoluble dietary fiber acts as a bulking agent, normalizing intestinal motility, preventing constipation while soluble fiber is associated with decreasing the intestinal absorption of cholesterol and glucose (Silveira Rodríguez, Monereo Megías, & Molina Baena, 2003). Furthermore, fibers have been successfully applied in improving the water holding capacity (WHC) and oil holding capacity (OHC). These characteristics can be useful in products that require hydration, to avoid syneresis, improve yield, stabilize emulsions, and modify texture and viscosity (Elleuch et al., 2011).

Traditionally, the fiber used as a functional ingredient is obtained from cereals. However, according to recent studies, fruits and vegetable byproducts still contain high levels of dietary fiber (Fernández-López, Sendra, Sayas-Barberá, Navarro, & Pérez-Alvarez, 2008) with the advantage of having considerable amounts of antioxidants. The application of byproducts has already been studied in meat products, such as lemon albedo (Aleson-Carbonell, Fernández-López, Pérez-Alvarez, & Kuri, 2005), passion fruit byproduct (López-Vargas, Fernández-López, Pérez-Álvarez, & Viuda-Martos, 2014), horchata byproducts (Sánchez-Zapata et al., 2010), and hazelnut pellicle (Turhan, Sagir, & Sule Ustun, 2005). However, to the best of our knowledge, there is lack of studies about the application of pineapple byproduct in meat products.

With a world production exceeding 24 million t (FAOSTAT, 2015), pineapple is a widely consumed tropical fruit. Besides the fresh fruit, most of its production is used for the manufacture of several products,

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such as juices, fruit salads, canned fruits and jams. According to Larrauri, Rupérez, and Calixto (1997), residues from pineapple processing represent 25–35% of the fruit, and they still have bioactive compounds. Martínez et al. (2012), studying pineapple byproducts, reported high fiber content (75.8% dry basis) with 75.2% and 0.6% corresponding to insoluble and soluble fiber, respectively, high water holding capacity and swelling capacity.

Vegetable oils are cholesterol free and they have higher proportion of unsaturated/saturated fatty acids compared with animal fats (Choi et al., 2009). Canola oil presents good lipid profile, having the lowest levels of saturated fatty acids (SFAs) (7.36%) compared with other vegetable oils, such as sunflower (10.30%), corn (12.94%), olive (13.80%), soybean (15.65%), and cottonseed (25.9%) oils, high levels of monounsaturated fatty acids (MUFAs) (63.27%), and intermediate levels of polyunsaturated fatty acids (PUFAs) (28.14%) (USDA, 2015). Its lipid composition has motivated studies based on their application in meat products as an alternative to minimize changes of the animal fat reduction, and also provide positive effects on consumer's health (Singh, Chatli, Biswas, & Sahoo, 2014; Pelser, Linssen, Legger, & Houben, 2007).

Thus, the aim of this study was to evaluate the effect of pineapple byproduct and canola oil as fat replacers on cooking properties and chemical, physicochemical, texture and sensory characteristics of low-fat beef burgers.

2. Material and methods

2.1. Byproduct preparation

Pineapple byproducts (peel and pomace) were obtained from a fruit and vegetable processing industry (Jundiaí, São Paulo, Brazil). At the industry, the fruits were sanitized with 200 ppm of sodium hypochlorite, rinsed with water and then passed through the pulp extractor, where the byproducts were collected. The materials were kept frozen until their transportation to the Laboratory of Food and Nutrition, "Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo" (ESALQ/USP — Piracicaba, SP, Brazil). Samples were freeze dried (EC Modulyo, EC Apparatus Inc., New York, USA), ground using a knife mill (Marconi, Piracicaba, SP, Brazil), passed through a 40-mesh sieve (420 μm) and stored at −18 °C. Before the burger processing, pineapple byproducts underwent a thermal treatment (100 °C, 2 h) in order to inactive the bromelain.

2.2. Burger manufacture

Fresh beef (moisture 77.24%, fat 1.29%) and back fat (moisture 12.06%, fat 84.09%) were obtained from the local market. Beef and fat were separately ground (Hobart 4B22-2, Troy, OH, USA) using a 0.8 cm plate and then beef was divided into 5 treatments. The first treatment was used as a conventional formulation (CN) and the fat content was adjusted to 20% by the addition of back fat. The second treatment was used as a low-fat control (CT) and the fat content was adjusted to 10%. For the other treatments, pineapple byproduct (1.5%) and/or canola oil emulsion (5%) were used and the fat content was also adjusted to 10% (Table 1). The concentration of the pineapple byproduct was selected based on a previous experiment that evaluated different concentrations of pineapple byproducts (1.0, 1.5, 2.0, 2.5%) and canola oil (5%) as fat substitutes in low-fat beef burger (Selani, Margiotta, Piedade, Contreras-Castillo, & Canniatti-Brazaca, 2015). The concentration of 1.5% was selected, which, according to the total dietary fiber of the pineapple byproduct (69.64 g/100 g dry basis, data not shown), corresponds to the addition of 1.04% of fiber in the formulation. Canola oil emulsion was prepared by mixing (Ultra Turrax IKA T18 basic, Wilmington, NC, USA) for 2 min, at 10,000 rpm, eight parts of mineral hot water (50–55 °C) with one part of isolated soy protein and then with 10 parts of canola oil for other 3 min, at 10,000 rpm (Muguerza, Gimeno, Ansorena, Bloukas, & Astiasarán, 2001).

Table 1
Formulation of beef burgers with addition of canola oil and pineapple byproducts.

Ingredients	Treatments (%)				
	CN	CT	PA	CO	PC
Beef meat	70	70	70	70	70
Back fat	20	10	10	10	10
Cold water	7.5	17.5	16	12.5	11
Canola oil emulsion	0	0	0	5	5
Pineapple byproduct	0	0	1.5	0	1.5
Salt	1.5	1.5	1.5	1.5	1.5
Mix for burger[a]	1	1	1	1	1

CN: conventional, with 20% fat; CT: control, with 10% fat; PA: with 10% fat and 1.5% of pineapple byproducts; CO: with 10% fat and 5% of canola oil; PC: with 10% fat, 1.5% of pineapple byproducts and 5% of canola oil.
[a] Commercial mix for burger: salt, maltodextrin, sodium polyphosphate, sodium erythorbate, natural spices and monosodium glutamate.

After the addition of the beef, fat, pineapple byproduct and canola oil emulsion, the treatments were mixed with salt (1.5%), a commercial mix for burger (salt, maltodextrin, sodium polyphosphate, sodium erythorbate, natural spices and monosodium glutamate) (IBRAC, Rio Claro, SP, Brazil) and cold water. The formulations were kneaded by hand for 5 min and then 100 g portions were manually shaped using a burger-maker, to give the dimensions of 10 cm diameter and 1 cm thickness. The burgers were then placed in polyethylene packages and stored under −18 °C until further analyses. Part of the analyses was performed in raw and cooked burgers. The cooking procedure occurred before these analyses, in a hot plate (150 °C) (Edanca, São Bernardo do Campo, SP, Brazil), until a meat core temperature of 75 °C. The processing occurred in triplicate (three independent burger processing).

2.3. Proximate composition

Moisture, ash, lipid (Soxhlet), and protein (Kjeldahl, N × 6.25) were determined in cooked burgers, in triplicate, according to AOAC (2010). Available carbohydrates were calculated by difference.

2.4. Physicochemical analysis

2.4.1. pH

The pH was determined using a potentiometer (Oakton pH 300 series 35,618, Vernon Hills, IL, USA) with automatic temperature compensation and glass penetration electrode (Digimed, Presidente Prudente, SP, Brazil). The analysis was performed on five raw and cooked samples of each treatment, with three readings in each sample.

2.4.2. Color evaluation

The color of raw and cooked burgers was determined using a colorimeter (Konica Minolta, Chroma Meter, CR-400, Mahwah, NJ, USA) with a measurement area of 8 mm in diameter, observation angle of 10° and illuminant C. The parameters were calibrated in a standard white porcelain with Y = 93.7, x = 0.3160 and y = 0.3323 and the following parameters were determined: lightness (L*), redness (a* ± red-green), and yellowness (b* ± yellow-blue). Hue (H*) and chroma (C*) were calculated according to Eqs. 1 and 2:

$$\text{Hue} = \tan^{-1} b*/a* \tag{1}$$

$$\text{Chroma} = \left(a*^2 + b*^2\right)^{1/2}. \tag{2}$$

To determine the color, a surface layer was removed from both sides of the product. The analysis was performed on five samples of each treatment, with three readings in each sample.

2.4.3. Water activity

Water activity (Aw) was measured in raw and cooked burgers at 25 °C using the analyzer Aqualab CX 2T (Decagon Devices Inc., Pullman, WA, USA). The analysis was performed in triplicate.

2.5. Cooking properties

Three beef burgers of each treatment were cooked according to the procedures previously described and then samples were cooled to room temperature (25 °C) before weighing.

Cooking loss (CL) was calculated as weight loss divided by original weight, expressed as a percentage. Moisture retention (Eq. 3), fat retention (Eq. 4), and diameter reduction (Eq. 5) were obtained according to Sánchez-Zapata et al. (2010):

$$\%\textbf{Moisture retention}: \frac{\text{Cooked weight} \cdot \%\text{Moisture in cooked burger}}{\text{Raw weight} \cdot \%\text{Moisture in raw burguer}} * 100 \tag{3}$$

$$\%\textbf{Fat retention}: \frac{\text{Cooked weight} \cdot \%\ \text{Fat in cooked burger}}{\text{Raw weight} \cdot \%\ \text{Fat in raw burguer}} * 100 \tag{4}$$

$$\%\textbf{Diameter reduction}: \frac{\text{Raw diameter} - \text{Cooked diameter}}{\text{Raw diameter}} * 100. \tag{5}$$

2.6. Texture analysis

Texture profile analysis (TPA) and Warner Bratzler shear force (WB) were determined using a Texture Analyzer TA-XT (Stable Micro Systems, Godalming, United Kingdom). Prior to the analyses, samples were cooked according to the procedures previously described and cooled. Both analyses were performed with samples at 25 °C.

For TPA, four burgers of each treatment were used and from each burger four cylindrical samples (2.5 cm) were taken. Then, samples were subjected to a two-cycle compression test, using a cylindrical probe of 3.5 cm diameter (P/35, Stable Micro Systems, Godalming, United Kingdom). Samples were compressed to 75% of their original height at a constant speed of 20 cm/min (pre-test speed and post-test speed: 40 cm/min). Hardness (N), springiness, cohesiveness, and chewiness were determined as described by Bourne (1978).

For WB, two 2.5 cm wide × 5.0 cm-long strips were removed per burger, and five burgers were used from each treatment. The Warner Bratzler blade set (HDP/WBV, Stable Micro Systems, Godalming, United Kingdom) was used and the crosshead speed of the test was 25 cm/min. The instrumental value obtained was the peak force (N).

2.7. Microbiological analysis

Microbiological analysis was performed after the samples were cooked to verify the hygienic quality of the sample processing according to the limits specified by the Agência Nacional de Vigilância Sanitária (Brazilian Health Surveillance Agency). Microbial counts were determined by diluting 25 g of sample in 225 mL of sterile peptone water (PW) (Difco Laboratories, Detroit, MI, USA) for *Escherichia coli*, thermotolerant coliforms, coagulase-positive staphylococci, and sulfite-reducing clostridia and in 225 mL of lactose broth (Difco Laboratories, Detroit, MI, USA) for *Salmonella*. Following dilution, samples were blended using a Stomacher (Seward Laboratory Systems, Bohemia, NY, USA), for 1 min. Further serial dilutions were prepared for microbial determinations.

Salmonella testing was performed by a pre-enrichment with lactose broth and then enriched samples were applied to the 1–2 test for *Salmonella* (BioControl Systems Inc., Bothell, WA, USA), according to the manufacturer's directions.

E. coli and thermotolerant coliforms were counted using the multiple-tube fermentation test and expressed as most probable number (MPN)/g sample. Coagulase-positive staphylococci were counted by inoculating samples onto the surface of sterile plates with Baird–Parker agar (Difco Laboratories, Detroit, MI, USA). Sulfite-reducing clostridia were counted by inoculating samples on sterile plates with sulfite–polymyxin–sulfadiazine agar (Himedia, Mumbai, India), overlayed with 5 mL of the same medium and incubated in plastic anaerobic jars (2.5 L) using AnaeroGen sachet (Oxoid, Hampshire, United Kingdom). The determinations were performed in duplicate and the counts expressed as colony forming unit (CFU)/g sample.

2.8. Quantitative descriptive analysis (QDA)

The quantitative descriptive analysis of the cooked burgers was approved by the Ethics Committee of Human Research of the ESALQ/USP (ESALQ/USP — Piracicaba, SP, Brazil) and developed in nine 2-h sessions, according to the method developed by (Stone, 1992). The QDA was determined by eight panelists, who were recruited from the students of the Departamento de Agroindústria, Alimentos e Nutrição/ESALQ/USP. In the first stage of the analysis, seventeen candidates agreed to participate, and a pre-selection was performed to evaluate their ability to discriminate tastes and odors through basic taste tests, odor recognition tests and sequential analysis using triangle tests. For the next stage thirteen panelists were selected.

For the descriptive terminology development, Kelly's Repertory Grid Method (Moskowitz, 1983) was used. All samples were presented in pairs, and the panelists described the similarities and differences between them for the attributes appearance, odor, flavor, and texture. A list of terms was obtained and through an open discussion with a panel leader, the panelists had to evaluate all of them and exclude the redundant terms. After that, the panel established, by a consensus, the definition of each attribute and its reference material (Table 2). In another session, all the references were presented and they were tasted by the panelists to attain a better understanding and a final agreement on how to measure all the attributes.

Different training sessions were conducted until the panel presents repeatability, agreement among the members and ability to discriminate samples (panel performance was considered satisfactory when the interactions of “assessor × session”, “assessor × sample” and “sample × session” were not significant). In this stage, eight panelists went to the final assessment of the QDA.

For the formal assessment, burgers were cooked as previously described. Samples were cut into cubes (2 cm × 2 cm × 2 cm), random coded with three-digit numbers and presented in a sequential monadic way, following a balanced complete block design (Macfie, Bratchell, Greenhoff, & Vallis, 1989). The evaluations were conducted in individual booths equipped with lighting fluorescent lamps using a non-structured 10 cm-long scale, which was anchored as light and dark (brown color), slight and a lot (cohesiveness, tenderness, springiness, juiciness) and none and intense (odor and flavor of beef burger). After training, formal assessment was carried out in duplicate (two sessions).

2.9. Experimental design and statistical analysis

The study was a randomized block design, with three blocks (each block corresponding to an independent burger processing). An analysis of variance (ANOVA) was carried out to analyze the results and the comparisons of treatments were performed by the Tukey's test ($P < 0.05$), using the software SAS.

For the QDA, a three-factor ANOVA for each descriptor was carried out on the trained assessor scores, considering sample, session, assessor and their interaction as sources of variation. Tukey's test ($P < 0.05$) was used to compare the treatments. QDA results were also evaluated by principal component analysis (PCA) in a correlation matrix with the data centered and scaled on the mean. This analysis was performed to

Table 2
Attributes, definitions and scale extremes used in the QDA of beef burgers.

Parameter	Attribute	Definitions	Scale extremes
External appearance	Brown color	Characteristic color of burger, ranging from light to dark brown	Light: chicken burger cooked until internal temperature of 75 °C Dark: beef burger cooked until internal temperature of 90 °C
Internal appearance	Cohesiveness	Uniform and compact appearance	Slight: cooked ground beef A lot: chicken sausage
Odor	Beef burger	Characteristic of commercial beef burger, made with beef, fat and seasonings	None: water Strong: commercial beef burger cooked until internal temperature of 75 °C
Texture	Tenderness	Force needed to obtain deformation and cutting of the product by compression between teeth	Slight: *Biceps femoris* steak, cooked until internal temperature of 90 °C A lot: *Psoas major* steak, cooked until internal temperature of 70 °C
	Springiness	Ability of the product to return to its original shape, after compression between teeth	Slight: hard candy A lot: gummy bears
	Juiciness	Amount of moisture/liquid released by the first bites	Slight: semitendinosus steaks, cooked until internal temperature of 90 °C A lot: *Psoas major* steak, cooked until internal temperature of 70 °C
Flavor	Beef burger	Characteristics of commercial beef burger, made with beef, fat and seasonings	None: water Strong: commercial beef burger cooked until internal temperature of 75 °C

study the relationship among the intensity of the evaluated attributes and to get a sample map based on the intensity of the sensory attributes. Sensory data were performed in the software R, using SensoMineR (Le & Husson, 2008) and XLSTAT.

3. Results and discussion

3.1. Proximate composition

Table 3 presents the fat content of raw burgers, and according to these values, it was possible to confirm that, despite the small variations, the fat amounts of each treatment were consistent with target levels. Conventional burgers, as expected, showed the highest fat amount. CO and PC were not significantly different, and due to the canola oil addition, they showed values slightly higher than the low-fat control and the treatment with pineapple byproducts.

Regarding the proximate composition of the cooked burgers, differences in moisture contents were mainly related to the amount of water added to the formulations. However, for the two treatments with pineapple byproducts, which presented the highest values (Table 3), the increment in moisture was probably related to the presence of fiber in the products, providing higher water retention to the burgers. Similar result was found by Choi et al. (2009) studying the addition of rice bran fiber and vegetable oils in meat batters. Protein content was significantly lower for PA and PC, which could be attributed to dilution effects resulting from pineapple byproduct addition to the formulations. Same effects were reported by López-Vargas et al. (2014) studying passion fruit albedo and by Sánchez-Zapata et al. (2010) with tiger nut fiber. As expected, conventional burgers had a significantly higher fat content compared with low-fat treatments. The differences between the results and the target fat levels (20% for CN, 10% for the low-fat treatments) were probably due to cooking effects: excessive fat loss in CN (low-fat retention, Table 5) that can be a result of the saturation of the protein:fat binding (difficulty of the protein matrix to hold the high amount of fat); and concentration of the compounds with the water loss in the other treatments. Ash content ranged from 3.84 to 4.33 and it was lower in the low-fat treatments probably because part of the fat was replaced by water. Different results were found by previous studies, which reported an increase in ash content when byproducts rich in fiber were added to burgers (López-Vargas et al., 2014; Sánchez-Zapata et al., 2010). Despite the addition of pineapple byproducts, carbohydrate levels were not affected by any of the formulations.

3.2. Physicochemical analysis

The differences in lightness (L^*), redness (a^*), yellowness (b^*), chroma (C^*) and hue angle (H^*) of raw burgers were significant (Table 4). CN and CO treatments resulted in lighter burgers, with L^* values of 49.10 and 47.19, respectively. Since conventional formulation had 10% more fat than low-fat treatments, it was expected that the color of its final product would be lighter. The addition of canola oil increased lightness of both CO and PC, however just CO presented values similar to the conventional. This effect can be explained by the study of Youssef and Barbut (2011), who reported that the increase in lightness of meat emulsion with canola oil was probably related to the much smaller canola oil globules, which reflect more light (larger surface area) than the larger animal fat globules. Similar results were found by Rodríguez-Carpena et al. (2012), studying the addition of avocado, sunflower, and olive oils in pork burgers. PA and PC were darker than the conventional burgers and they showed a decrease in redness compared with all of the other treatments, indicating that the color of the pineapple byproducts affected the characteristic color of the burgers. Darkening of samples was found by Choi et al. (2012), with the addition of seaweed (*Laminaria japonica*) in reduced-fat pork burger and a decrease in redness was reported by Sánchez-Zapata et al. (2010) in pork burger with tiger nut fiber. Yellowness was not significantly affected by both canola oil and pineapple byproducts. Both treatments with pineapple byproducts had lower chroma (C^*) values compared with CN, indicating a decrease in color intensity. Regarding hue angle (H^*), PA and PC presented the highest values and were not significantly different from the conventional

Table 3
Fat content of raw burger and proximate composition (g/100 g) of cooked burgers with addition of fruit byproducts and canola oil (mean ± standard deviation).

Treatment	Raw burger	Cooked burger				
	Fat	Fat	Moisture	Protein	Ash	Carbohydrates
CN	17.79 ± 1.11^{a}	16.28 ± 2.03^{a}	53.50 ± 2.09^{c}	22.89 ± 1.32^{a}	4.33 ± 0.32^{a}	3.00 ± 1.18^{a}
CT	8.48 ± 0.65^{d}	12.27 ± 1.37^{b}	58.09 ± 1.28^{ab}	22.33 ± 0.90^{a}	4.14 ± 0.42^{ab}	3.16 ± 0.73^{a}
PA	9.02 ± 0.79^{cd}	11.98 ± 0.17^{b}	61.80 ± 1.62^{a}	18.49 ± 0.95^{b}	3.84 ± 0.11^{b}	2.86 ± 0.69^{a}
CO	10.92 ± 0.34^{bc}	12.53 ± 1.13^{b}	56.95 ± 1.86^{bc}	22.83 ± 0.84^{a}	4.23 ± 0.11^{ab}	3.46 ± 1.12^{a}
PC	11.24 ± 0.66^{b}	12.93 ± 1.04^{b}	58.74 ± 2.30^{ab}	19.73 ± 1.40^{b}	4.11 ± 0.21^{ab}	3.46 ± 0.74^{a}

Carbohydrates by difference.
Different letters in the same column differ significantly ($P < 0.05$) by the Tukey's test.
CN: conventional, with 20% fat; CT: control, with 10% fat; PA: with 10% fat and 1.5% of pineapple byproduct; CO: with 10% fat and 5% of canola oil; PC: with 10% fat, 1.5% of pineapple byproducts and 5% of canola oil.

Table 4
Physicochemical properties of raw and cooked burgers with addition of fruit byproducts and canola oil (mean ± standard deviation).

	Lightness (L*)	Redness (a*)	Yellowness (b*)	Chroma (C*)	Hue (H*)	pH	Aw
Raw burger							
CN	49.10 ± 5.39^{a}	23.99 ± 1.30^{a}	14.10 ± 1.08^{a}	27.84 ± 1.15^{a}	30.47 ± 2.51^{abc}	6.20 ± 0.03^{a}	0.97 ± 0.00^{a}
CT	43.43 ± 3.63^{bc}	23.30 ± 2.19^{a}	12.74 ± 0.91^{a}	26.56 ± 2.29^{ab}	28.70 ± 1.32^{c}	6.17 ± 0.08^{a}	0.97 ± 0.00^{a}
PA	42.84 ± 4.02^{c}	19.50 ± 2.44^{b}	12.82 ± 1.43^{a}	23.37 ± 2.35^{c}	33.43 ± 3.88^{ab}	5.97 ± 0.08^{b}	0.97 ± 0.00^{a}
CO	47.19 ± 3.71^{ab}	24.20 ± 3.30^{a}	14.12 ± 2.11^{a}	28.03 ± 3.86^{a}	30.25 ± 1.35^{bc}	6.18 ± 0.10^{a}	0.97 ± 0.00^{a}
PC	44.84 ± 3.56^{bc}	19.84 ± 2.08^{b}	13.45 ± 1.50^{a}	23.97 ± 2.44^{bc}	34.15 ± 1.84^{a}	6.01 ± 0.08^{b}	0.97 ± 0.00^{a}
Cooked burger							
CN	45.96 ± 0.99^{a}	9.94 ± 0.93^{ab}	9.49 ± 1.18^{a}	13.79 ± 0.92^{a}	44.52 ± 3.77^{a}	6.78 ± 0.17^{a}	0.96 ± 0.00^{a}
CT	46.21 ± 1.06^{a}	10.28 ± 0.27^{a}	9.69 ± 0.21^{a}	14.27 ± 0.37^{a}	44.32 ± 2.10^{a}	6.75 ± 0.15^{a}	0.96 ± 0.00^{a}
PA	48.52 ± 2.76^{a}	8.97 ± 0.54^{b}	10.94 ± 0.36^{a}	14.21 ± 0.19^{a}	50.34 ± 3.01^{a}	6.52 ± 0.10^{b}	0.96 ± 0.00^{a}
CO	45.09 ± 2.67^{a}	9.97 ± 0.16^{ab}	10.09 ± 1.41^{a}	14.42 ± 0.52^{a}	46.38 ± 2.58^{a}	6.76 ± 0.17^{a}	0.96 ± 0.00^{a}
PC	46.68 ± 3.54^{a}	9.13 ± 0.82^{b}	10.45 ± 1.64^{a}	14.25 ± 0.44^{a}	49.38 ± 5.58^{a}	6.54 ± 0.14^{b}	0.96 ± 0.00^{a}

Different letters in the same column differ significantly ($P < 0.05$) by the Tukey's test.
CN: conventional, with 20% fat; CT: control, with 10% fat; PA: with 10% fat and 1.5% of pineapple byproducts; CO: with 10% fat and 5% of canola oil; PC: with 10% fat, 1.5% of pineapple byproducts and 5% of canola oil.

burgers, indicating that these treatments were closer to the yellow axis compared with CT. These results could be due to the fat color (light yellow) in CN and the influence of the pineapple byproduct color (b* = 20.65) in PA and PC. Increase in C* values of pork burgers with tiger nut fiber was found by Sánchez-Zapata et al. (2010), corroborating with this study.

After cooking, there were no significant differences among treatments for the L*, b*, C* and H* color parameters (Table 4). According to Sánchez-Zapata et al. (2010) the alterations caused by the cooking process (Maillard reaction, protein denaturation, and fat and water loss) could mask some undesirable color changes induced by formulation. This could explain the results of the present study, in which the fat reduction and the addition of pineapple byproducts and canola oil caused some color changes in raw samples, however in cooked samples no differences were found in lightness, yellowness, chroma and hue angle. Regarding a* value, the three treatments with addition of fat substitutes (PA, CO, and PC) showed positive results, since their redness was similar to the conventional. The low-fat control (CT) had the highest value probably because this treatment did not receive any additional ingredient and due to its high cooking loss (Table 5), resulting in protein concentration, and consequently, higher redness.

The pH of raw and cooked samples presented the same tendency, showing that the incorporation of pineapple byproducts in burgers significantly decreased the pH values compared with those of the other treatments (Table 4). This pH reduction is certainly a result of the characteristics of the pineapple byproducts that had a pH of 4.08 and a titratable acidity of 1.90 g citric acid/100 g (data not shown). Similarly, López-Vargas et al. (2014) found a pH decrease in burgers with addition of passion fruit albedo. Even with fiber addition, no differences were observed in water activity of raw and cooked burgers. This result is in agreement with the study of Aleson-Carbonell et al. (2005) with lemon albedo addition in beef burgers.

3.3. Cooking properties

PA and PC presented the lowest cooking loss (Table 5), and were significantly different from the other formulations. This is a result of the addition of the fruit byproducts rich in fiber (69.64% dietary fiber, data not shown) that presents the property to hold water and fat, reducing the fluid loss. Significantly lower cooking loss (or higher cooking yield) of burgers with fiber was also found in studies with wakame addition (brown seaweed, high in fiber) and olive oil (López-López, Cofrades, Yakan, Solas, & Jiménez-Colmenero, 2010) and with lemon albedo (Aleson-Carbonell et al., 2005).

Canola oil addition did not seem to interfere in cooking loss, since there was no significant difference between CO and the conventional burger. Different results were found by Dzudie, Kouebou, Essia-Ngang, and Mbofung (2004), who reported higher cooking loss for beef patties formulated with ground-nut and maize oils (20%, not emulsified) in comparison with animal fat treatments (20%) and by Youssef and Barbut (2011) who found that meat emulsions with canola oil showed lower fluid losses compared with the corresponding beef fat treatments. Differences between studies may be due to the amount of animal fat replaced, percentage and type of vegetable oil studied, as well as the method of vegetable oil incorporation to the product.

As observed for cooking loss, PA and PC presented the highest values of moisture and fat retention and no differences were observed among conventional and canola oil added burgers (Table 5). The results are probably related to the functional properties of the fibers contained in the pineapple byproducts (WHC: 4.96 g water/g freeze-dried sample, OHC: 1.85 g oil/g freeze-dried sample, data not shown), which avoided the excessive release of these components during cooking. The results are consistent with those reported by Sánchez-Zapata et al. (2010) studying horchata byproducts and by Aleson-Carbonell et al. (2005) with a lemon albedo. Furthermore, differences of fat retention could

Table 5
Cooking properties of burgers with addition of pineapple byproducts and canola oil (mean ± standard deviation).

Treatments	Cooking loss (%)	Moisture retention (%)	Fat retention (%)	Diameter reduction (%)
CN	39.15 ± 2.04^{a}	52.30 ± 1.09^{bc}	57.80 ± 5.84^{b}	27.58 ± 2.25^{a}
CT	41.33 ± 0.61^{a}	46.95 ± 1.24^{c}	85.20 ± 7.14^{a}	26.81 ± 2.42^{a}
PA	28.01 ± 3.83^{b}	63.39 ± 4.98^{a}	89.79 ± 1.95^{a}	18.79 ± 4.95^{b}
CO	40.79 ± 1.10^{a}	48.96 ± 2.83^{c}	68.24 ± 5.91^{b}	27.05 ± 1.95^{a}
PC	30.92 ± 1.56^{b}	59.52 ± 3.82^{ab}	82.41 ± 11.87^{a}	20.45 ± 4.12^{b}

Different letters in the same column differ significantly ($P < 0.05$) by the Tukey's test.
CN: conventional, with 20% fat; CT: control, with 10% fat; PA: with 10% fat and 1.5% of pineapple byproducts; CO: with 10% fat and 5% of canola oil; PC: with 10% fat, 1.5% of pineapple byproducts and 5% of canola oil.

also have been caused by the capacity of the protein matrix to retain lipids. The lower fat retention in the CN was probably due to its higher fat content, resulting in insufficient amounts of meat proteins to hold all the fat added. For CO, the extra amount of fat provided by the canola oil addition may have caused the low-fat retention.

The diameter reduction is the result of the denaturation of meat proteins with the loss of water and fat (Besbes, Attia, Deroanne, Makni, & Blecker, 2008). Since PA and PC showed the highest values of moisture and fat retention, it was expected that both treatments would present lower diameter reduction. Treatments without fiber addition reduced almost 8% more the burger diameter compared with the treatments with pineapple byproducts (Table 5). Thus, the fruit byproducts rich in fiber promoted desirable effects, minimizing the common shape changes of comminuted products. Turhan et al. (2005) reported the same effect in burgers with an addition of hazelnut pellicle.

3.4. Texture analysis

TPA hardness is defined as the maximum force required to compress the sample (Bourne, 1978), while WB shear force is obtained by the maximum force required to shear them. Due to this, both WB shear force and TPA hardness are usually used to predict tenderness in meats.

According to hardness results, CN and CT burgers presented the lowest and the highest values, respectively. Since fat provides flavor, tenderness and juiciness to food products (Keeton, 1994), its reduction in the burgers studied here led to development of harder products (Table 6). Furthermore, according to the study of Gao, Zhang, and Zhou (2014), hardness varied inversely with moisture retention of the meat product. Thus, since CT had the lowest moisture retention, this fact may also have contributed for obtaining harder products.

Treatments with fiber addition (PA and PC), even showing high moisture and fat retention (Table 5) and a slight decrease in hardness compared with the other low-fat formulations, were significantly harder than the conventional products. This result is in agreement with the study of Choi et al. (2009), who found that hardness of control meat batters (30% animal fat) was lower than those found in reduced-fat meat batters (10% animal fat) containing vegetable oils and rice bran fiber. However, in another study of Choi et al. (2012), they found a different result, with a decrease in hardness when fat was reduced and *L. japonica* (DF: 51.23%) was added to pork patties. Since hardening and softening have been observed when fiber is added to meat products, these results may be due to the amount and characteristics of each type of fiber used, as well as the type of meat product studied.

On the other hand, for WB shear force, there was no significant difference among CN and the low-fat treatments with pineapple byproduct addition. The similar shear force values of PA and PC in relation to the conventional burger may have been caused by the presence of fiber in pineapple byproducts, which contributed to an increase in moisture and fat retention of the burgers, resulting in a tender product.

Regarding the effects of the canola oil addition, CO was significantly harder than CN in both methods. This result is in accordance with the study of Youssef and Barbut (2011), who found an increase in hardness of cooked meat batters with canola oil addition. According to Youssef and Barbut (2010), when canola oil is used, the fat globules formed are smaller than those obtained from animal fat. With a higher surface area, canola oil globules, covered by proteins, allows more bonding to the matrix, resulting in firmer products.

Despite the different results of TPA hardness and WB shear force, mainly regarding pineapple byproduct addition, it was possible to observe that the fiber presence in beef burgers showed good results, minimizing the negative hardening of products with fat reduction.

Springiness was not affected either by the fat reduction or by the canola oil and pineapple byproduct addition. Similar results were found in pork patties with rice flour (Gao et al., 2014) and in pork burgers with avocado, sunflower and olive oils (Rodríguez-Carpena et al., 2012).

Conventional burgers had the highest cohesiveness value and it was significantly different from all the low-fat treatments. These treatments present lower fat:protein ratio, which may have led to a higher amount of available proteins to form denser protein network (Youssef, Barbut, & Smith, 2011), resulting in the development of a more cohesive product. Similar result was found in low-fat meat emulsion with vegetable oils and rice bran fiber (Choi et al., 2009).

For chewiness, there was no difference among CT, PA, CO, and PC, however they were all less chewy than conventional burgers. The higher chewiness of low-fat products is probably related to the fat reduction, and consequently, to the other texture parameters already discussed. Samples with higher hardness and cohesiveness probably need more work to masticate them until swallowing. Higher chewiness of low-fat meat emulsion with sunflower seed oil and makgeolli lees fiber compared with control was reported in a previous study (Choi et al., 2013).

3.5. Microbiological analysis

The microbial counts of all treatments were <2 MNP/g for thermotolerant coliforms and *E. coli*, <10 CFU/g for sulfite-reducing clostridia, $<10^2$ for coagulase-positive staphylococci, and absence of *Salmonella* in 25 g. All treatments showed counts within the limits established by the Agência Nacional de Vigilância Sanitária (Brazilian Health Surveillance Agency) thermotolerant coliforms: 10^3 MPN/g, sulfite-reducing clostridia: 5×10^2 CFU/g, coagulase-positive staphylococci: 3×10^3 CFU/g, and *Salmonella*: absence/25 g). In spite of the higher moisture retention observed in PA and PC, microbial growth of the burgers was not affected by the addition of pineapple byproducts. According to the microbial counts, in the given experimental conditions, the burgers developed here were safe and fit for consumption from a microbiological standpoint.

3.6. Quantitative descriptive analysis

The results of the QDA showed a significant effect for the attributes brown color, cohesiveness and juiciness.

PC and the CN showed similar intensity of brown color and the highest scores for this attribute, with values of 7.76 and 7.65, respectively (Table 7). Among the treatments with fat reduction, PA showed the lowest score, indicating that the addition of pineapple byproduct

Table 6
Textural properties and Warner Bratzler shear force of cooked burgers with addition of pineapple byproducts and canola oil (mean ± standard deviation).

Treatments	Hardness (N)	Springiness	Cohesiveness	Chewiness	WB (N)
CN	129.45 ± 4.11^b	0.67 ± 0.04^a	0.32 ± 0.02^b	2834.63 ± 122.44^b	18.03 ± 1.86^b
CT	208.09 ± 7.85^a	0.75 ± 0.05^a	0.42 ± 0.02^a	6645.44 ± 854.21^a	23.56 ± 1.96^a
PA	185.37 ± 5.67^a	0.74 ± 0.04^a	0.41 ± 0.03^a	5708.87 ± 47.85^a	21.10 ± 0.28^{ab}
CO	204.84 ± 5.67^a	0.76 ± 0.03^a	0.46 ± 0.02^a	6841.82 ± 905.22^a	21.86 ± 1.60^a
PC	194.90 ± 10.43^a	0.76 ± 0.01^a	0.45 ± 0.01^a	6705.92 ± 252.36^a	21.19 ± 0.25^{ab}

WB: Warner Bratzler shear force.
Different letters in the same column differ significantly ($P < 0.05$) by the Tukey's test.
CN: conventional, with 20% fat; CT: control, with 10% fat; PA: with 10% fat and 1.5% of pineapple byproducts; CO: with 10% fat and 5% of canola oil; PC: with 10% fat, 1.5% of pineapple byproducts and 5% of canola oil.

alone, due to its light color (lightness = 73.45) and high water holding capacity (4.96 g water/g dry sample, increasing moisture retention of the burger), resulted in burgers with a lighter brown color. The decrease in color intensity was also observed in pork burger with passion fruit albedo (López-Vargas et al., 2014). Regarding CO scores, the low values may be explained by the relationship between the size of the fat globules and the light reflectance. According to Youssef et al. (2011), the lighter appearance of products with canola oil is due to their smaller fat globules compared with those of animal fat.

There was a significant increase in cohesiveness with the fat reduction, however the addition of pineapple byproducts (PA and PC) positively affected the products, resulting in burgers with similar scores to CN. Youssef and Barbut (2011) reported that cohesiveness tends to decrease as fat content increases and in another study Youssef et al. (2011) found that high values of cohesiveness could be related to high cooking loss, leading to protein concentration, and the development of a more cohesive protein matrix. This may explain the results of the present study, since CN had 10% more fat than the other treatments, and among the low-fat treatments, PA and PC showed high fat retention and the lowest values of cooking loss.

Regarding juiciness, conventional burger had the highest score and it was not significantly different from PA, CO and PC. These results showed that fiber from pineapple byproducts and/or canola oil addition improved juiciness of low-fat beef burgers. The high juiciness of PA and PC indicated that the fiber from pineapple byproducts retained the appropriate amount of moisture and fat to assure a juicy product. In treatments with canola oil (CO and PC), since fat provides juiciness to food products, the addition of another source of fat improved this sensory aspect in the products. The results also showed that CT presented the lowest value, indicating that the simple fat reduction, without adding any fat substitute, negatively affect the meat product. Choi et al. (2012) reported that juiciness scores of reduced-fat pork patties containing 1% and 3% *L. japonica* powder (fiber = 51.23%) were significantly higher than the control, and that reduced-fat pork patties without L. japonica showed the lowest value.

Other positive aspect observed in the QDA was the fact that tenderness, springiness, and odor and flavor of the burgers were not affected by pineapple byproduct and canola oil addition.

According to the PCA, the sum of the principal components 1 and 2 (PC1 and PC2) accounted for 83.66% of the variations of the data.

PC1 explained the majority of the variations (59.64%) and as expected, conventional product was positioned on the opposite side of the low-fat control. CN and PC were located on the right side, indicating that they had higher intensity of brown color, tenderness, juiciness, odor and flavor of beef burger (Fig. 1). These are important results, showing that the addition of fiber rich pineapple byproducts associated with canola oil positively influenced juiciness and tenderness, two of the most affected sensory parameters in products with fat reduction. Furthermore, the use of these two ingredients did not affect the odor and flavor of the burger. Cohesiveness and springiness, attributes negatively correlated to the PC 1, were higher in CT, CO and PA. This is in accordance with Keeton (1994), who described that as fat content of meat products declines, cohesiveness and springiness increase.

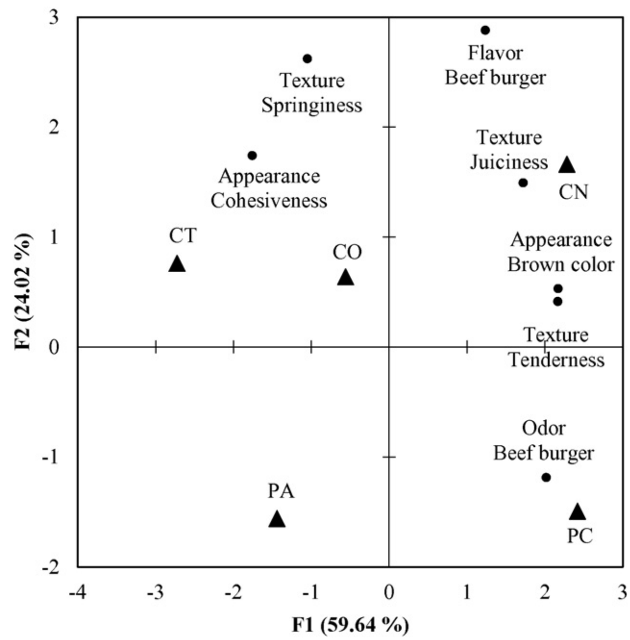

Fig. 1. Principal component analysis of the sensory attributes of beef burgers.

PC2 explained 24.02% of the variance and was positively correlated with all the texture and appearance attributes, as well as the flavor of beef burger, presenting CN, CT, and CO located at the top part of the graphic. The negative values were observed for odor of beef burger, indicating that PA and PC presented higher intensity of this attribute.

4. Conclusions

The use of pineapple byproducts was found to be effective in improving the cooking characteristics of the product, affecting positively the yield and appearance of low-fat burgers. Color of cooked low-fat burgers with addition of canola oil and/or pineapple byproducts was not affected, which is a significant result considering the importance of this attribute to the consumer's acceptability. In spite of the texture alterations observed in all the low-fat treatments (they were harder, chewier, and more cohesive than CN), the ones with pineapple byproduct addition (PA and PC) stood out, since according to the WB shear force results, they were as tender as the full-fat burger. QDA analysis showed that PC was not different from the conventional burger in any of the attributes evaluated, indicating that the use of the two fat replacers together can be a suitable choice to minimize the sensory alterations of the fat reduction in beef burgers.

Table 7
Quantitative descriptive analysis scores of beef burgers with addition of pineapple byproducts and canola oil (mean ± standard deviation).

Parameter	Attribute	Treatments				
		CN	CT	PA	CO	PC
External appearance	Brown color	7.65 ± 0.85^a	6.05 ± 1.52^b	5.71 ± 1.16^b	6.32 ± 1.19^b	7.76 ± 0.81^a
Internal appearance	Cohesiveness	5.58 ± 1.40^b	7.11 ± 0.80^a	5.76 ± 1.16^b	7.12 ± 0.84^a	5.11 ± 1.48^b
Odor	Beef burger	5.99 ± 1.77^a	5.52 ± 2.31^a	5.81 ± 1.89^a	5.57 ± 2.36^a	6.08 ± 1.87^a
Texture	Tenderness	7.49 ± 0.98^a	6.72 ± 1.21^a	6.90 ± 1.53^a	7.31 ± 1.54^a	7.49 ± 1.07^a
	Springiness	6.33 ± 1.28^a	6.37 ± 0.96^a	6.03 ± 1.05^a	5.92 ± 1.64^a	5.49 ± 1.82^a
	Juiciness	7.39 ± 0.70^a	6.11 ± 1.27^b	6.41 ± 1.20^{ab}	7.21 ± 0.82^a	6.84 ± 0.98^a
Flavor	Beef burger	6.70 ± 1.06^a	6.37 ± 1.64^a	6.01 ± 1.62^a	6.29 ± 1.81^a	6.33 ± 1.39^a

Different letters in the same column differ significantly ($P < 0.05$) by the Tukey's test.
CN: conventional, with 20% fat; CT: control, with 10% fat; PA: with 10% fat and 1.5% of pineapple byproducts; CO: with 10% fat and 5% of canola oil; PC: with 10% fat, 1.5% of pineapple byproducts and 5% of canola oil.

The results of this study highlight the application of pineapple byproduct associated with canola oil emulsion as promising fat replacers in beef burger, opening the possibility of a new application for this fruit byproduct.

Additional studies are recommended to evaluate alternatives for the freeze-drying process in the byproduct preparation, such as the study of different time–temperature binomials in oven-drying, in order to optimize the obtaining of pineapple byproducts and to increase their feasibility of use in the meat industry.

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