Characterisation and potential application of pineapple pomace in an extruded product for fibre enhancement

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ABSTRACT

This study characterised pineapple pomace (PP) and evaluated its application in extrusion to enhance fibre content of the final product. The pomace had low fat (0.61%) and high dietary fibre (45.22%), showing its potential for fibre enrichment of nutritionally poor products, as some extruded snacks. Results also showed low microbiological counts, water activity, and pH indicating good microbiological quality and low risk of physicochemical deterioration. During extrusion, pomace (0%, 10.5% and 21%), moisture (14%, 15% and 16%) and temperature (140 and 160 °C) were evaluated. The PP addition decreased expansion and luminosity; while increasing redness of the extrudates compared to the control (0% pomace/14% moisture/140 °C). When hardness, yellowness, water absorption, and bulk density were compared to the control, there was no effect ($p > 0.05$) of 10.5% PP addition on the extrudates, indicating that, at this level, PP could be added without affecting the properties of the final extruded product.

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1. Introduction

Pineapple world production reached 21.8 million of tons in 2011 (FAO, 2013), and most of its production is used for processing as fruits salads, juices, concentrates, and jams. During processing, large amounts of byproducts, consisting mainly of peel and pomace are generated, representing about 25–35% of the fruit weight (Larrauri, Rupérez, & Calixto, 1997). Since most of these byproducts have no specific destination, they may be inappropriately disposed causing environmental issues. Consequently, it is of vital importance to reuse industrial byproducts in order to improve the process economics and its sustainability.

It is well-known that dietary fibre plays an important role in human health, promoting several physiological and metabolic positive effects (Raninen, Lappi, Mykkänen, & Poutanen, 2011). The insoluble dietary fibre as a bulking agent, normalising intestinal motility, preventing constipation while soluble fibre is associated to decreasing the intestinal absorption of cholesterol and glucose (Rodríguez, Megías, & Baena, 2003). Due to all of these benefits of dietary fibre intake, a tendency in the development of products enriched with fibre or with specific fibre claims has already been observed for some time. According to the Food and Drug Administration (FDA) (2013), to have a product with a "high source of fibre" and "good source of fibre" claim, it must contain, respectively, 20% or more fibre and 10–19% of fibre of the recommended daily value for dietary fibre in a serving size.

About 76% of pineapple byproduct (peel and heart) is fibre, from which 99.2% is the insoluble fraction and 0.8% is the soluble fraction (Martínez et al., 2012). As pineapple pomace contains valuable sources of dietary fibre, they could be used as a potential food ingredient to improve nutritional quality of foods. Furthermore, fibres have technological properties, such as water holding capacity (WHC), swelling capacity (SWC) and oil holding capacity, which can be useful in products that require hydration, to avoid syneresis, improve yield, stabilize high fat food products and emulsions, and also to modify texture and viscosity (Elleuch et al., 2011). One alternative would be to use these byproducts as ingredients in selected food process, i.e. extrusion processing.

Extrusion is an attractive choice because its versatility (wide range of food products applications), high productivity, relative low cost, energy efficiency and lack of effluents (Altan, McCarthy, & Maskan, 2008). Furthermore, extrusion-cooked products tend to be nutritionally poor since they are energy dense, and low in health promoting ingredients. The extrusion process itself

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promotes the depolymerisation of the starch, leading to an increase in the amount of easily digestible carbohydrates and resulting in a product with high glycemic index (Brennan, Derbyshire, Tiwari, & Brennan, 2013a).

Due to the characteristics of these products, some studies have evaluated the addition of food processing byproducts in extruded foods as source of fibre and bioactive compounds. The byproducts include orange peel, grape seed and tomato pomace (Yağcı & Göğüş, 2008); a mixture of cauliflower florets, curd, stem and leaves (Stojceska, Ainsworth, Plunkett, İbanoğlu, & İbanoğlu, 2008); and carrot pomace (Kumar, Sarkar, & Sharma, 2010). The addition of these byproducts promoted some alterations in the characteristics of the extrudates, but in all of the studies, good sensory acceptance was observed. Brennan, Derbyshire, Tiwari, and Brennan (2013b), used β-glucan rich materials from mushroom and barley processing as ingredients in extruded snacks and reported that the inclusion of this fibre promoted a reduction in the glycemic response.

Since pineapple processing produces significant amount of fibre rich pomace and currently there is lack of studies about its application in extruded products, the use of this byproduct in extrusion would be an interesting option as fibre enrichment. Besides, it would benefit the pineapple processing operations by making them more economically sustainable. Thus, the objective of this study was to characterise and evaluate the performance of pineapple pomace as an ingredient in extruded products.

2. Materials and methods

2.1. Production of pineapple pomace

Three different batches of mature pineapple (*Annanas comosus*), variety Gold (Del Monte Gold, Costa Rica), were purchased from local stores in Lincoln, NE, USA, during September 2012. To produce the byproduct, referred herein simply as pomace, fruits were processed at The Food Processing Center Pilot Plants of the University of Nebraska-Lincoln. First, the fruits were sanitized with 200 ppm of sodium hypochlorite, rinsed with water, and cut by hand into small pieces with peel. The pieces were introduced in a juice extractor (Speed Troll, Sterling Electric Inc., Irvine, CA, USA), where the juice was expelled and the pomace collected. The pineapple pomace (PP) (peel and pomace) was freeze-dried (Thermovac, Long Island, NY, USA) for 72 h under vacuum condition, ground using a knife mill (Mini Mill, Thomas Wiley, Swedesboro, NJ, USA), passed through a 40-mesh stainless steel sieve (420 μm), and stored into sealed plastic containers at −20 °C for further analyses. The particle size of these samples (Table 1) was determined in triplicate by laser diffraction in a Malvern Mastersizer 3000 (Malvern Instruments, Worcestershire, UK), using the dry dispersion method (Aero S dispersion cell), with a refractive index of 1.53, an air pressure of 4 bar and a sample feed of 50%.

Table 1
Particle size distribution of freeze-dried pineapple pomace (Average ± SD).

Size (μm)	% Undersize particles[*]
211	48.94 ± 2.13
454	87.13 ± 0.30
666	97.06 ± 0.38
859	99.05 ± 0.43
1110	99.51 ± 0.36
3080	100.00 ± 0.00

[*] Percentage of particles with diameter under the size (μm) described in the first column of this table.

2.2. Characterisation of pineapple pomace

2.2.1. Chemical analyses

Ash was determined according to AOAC 940.26 ((2000)), using a Thermolyne 30400 Furnace (Thermo Scientific, Waltham, MA, USA). Moisture was determined using a vacuum Thermolyne Oven Series 9000 (Thermo Scientific, Waltham, MA, USA) following AOAC 924.06 (2000). Soluble (SDF) and insoluble dietary fibre (IDF) were determined according to AOAC 960.52 (2000). Protein was calculated from the nitrogen content by the Dumas combustion method (Leco FP-528, Leco Corporation, St. Joseph, MI, USA) using a conversion factor of 6.25 and fat was determined by the Soxtec method (Soxtec 2043, Foss, Hillerød, Denmark), both according to the manufacturer's instructions. Carbohydrate content was calculated by difference. The analyses were carried in triplicate.

2.2.2. Physicochemical analyses

The pH of the samples was measured in a suspension obtained from a blend of 10 g of sample with 100 mL of deionised water, using a pH metre (Orion 2 Star, Thermo Electron Corporation, Beverly, MA, USA). Acidity was determined by titration with 0.1 N sodium hydroxide and the results were reported as g of citric acid/100 g of sample. Water activity (Aw) was determined using an Aqualab instrument (Aqualab Series 3TE, Decagon devices Inc., Pullman, WA, USA) at 25 °C. Colour was measured with a colorimeter (Minolta CR-300, Konica Minolta, Osaka, Japan), with D65 as illuminant, based in the CIELAB L^*, a^*, b^* colour space. The instrument was calibrated using a colour standard (white), with $Y = 92.7$, $x = 0.3162$ and $y = 0.3325$, provided by the manufacturer. Colour readings were taken in different points on the surface of the byproduct powder. The analyses were carried in triplicate.

2.2.3. Functional properties

Water holding capacity (WHC) and oil holding capacity (OHC) were determined in triplicate by the method described by Carcea-Bencini (1986), with the following modifications. One gram of pomace sample was stirred in 10 mL of distiled water (for WHC) or canola oil (Pure Wesson, ConAgra Foods, Omaha, NE, USA) (for OHC), centrifuged (Sorvall Legend XTR Thermo Scientific, Waltham, MA, USA) at 2200g for 30 min and the supernatant was carefully eliminated. Water holding capacity was reported as the number of grams of water held by 1 g of sample and oil holding capacity was reported as the number of grams of oil held by 1 g of sample.

2.2.4. Microbiological analysis

Microbial counts were determined by diluting 25 g of sample in 225 mL of phosphate sterile buffered peptone water (BPW) (Acumedia, Lansing, MI, USA) to achieve the 1:10 dilution. Following dilution, samples were blended using a Stomacher (Seward Laboratory Systems, Bohemia, NY, USA), for 1 min. Further serial dilutions were prepared in BPW for all of the microbial determinations. Total plate counts (TPC) were determined by plating the diluted samples on APC Petrifilm plates (3 M, St. Paul, MN, USA) followed by incubation at 35 °C for 48 h. *Escherichia coli* and thermotolerant coliforms were counted by plating samples on E. coli/ coliform petrifilm plates (3 M, St. Paul, MN, USA) following incubation at 45 °C for 24 h. Molds and yeasts counts were determined after plating samples on Dichloran Rose Bengal Chloramphenicol agar (DRBC) (Acumedia, Lansing, MI, USA) and incubating at 25 °C for 5 days. All these determinations were carried in duplicate for each dilution. *Salmonella* testing was performed by a pre-enrichment with BPW at 37 °C for 24 h, followed by a selective enrichment step with Tetrathionate Broth (TTB) (Acumedia, Lansing, MI, USA) at 41 °C for 24 h. Enriched samples were then

applied to a pathogen-specific test strips (RapidCheck, SDIX Newark, DE, USA), according to the manufacturer's directions.

2.3. Extrusion experiments

2.3.1. Blend preparation

Corn flour (Bunge Milling, St. Louis, MO, USA) was replaced by pineapple pomace (dry basis) at levels of 21% and 10.5%. These levels were chosen with the aim to deliver 10% (claim of "good source of fibre") (FDA, 2013) and 5% of the recommended daily value for dietary fibre (25 g/day) in a serving size (28.35 g). The treatments were adjusted to moisture levels of 14, 15 and 16% (w/w) in a mixer (Hobart, Troy, OH, USA) for 5 min. After mixing, the samples were placed in polypropylene plastic bags (Uline Poly Bags, S-1255) and stored at 4 °C overnight to ensure homogeneous moisture distribution.

2.3.2. Extrusion

Three extrusion trials were done using a single screw laboratory extruder (C.W. Brabender, model 2003 GR-8, South Hackensack, NJ, USA) with a die opening of 3 mm and a screw speed of 220 rpm.

The extruder screw had a compression ratio of 3:1, a length/diameter ratio of 20/1, length of 38 cm, and a diameter of 19 mm. The temperature of the first (feed) zone was set to 80 °C, while the second (metering) was set to 90 °C for all trials. Two temperatures at the third (compression) zone were evaluated: 140 and 160 °C. When the extrusion response parameters were stable, extrudates were collected for about 3 min. The samples were dried for 10 min at 100 °C in a drier (Wenger, Sabetha, KS, USA) to standardise the moisture for texture analysis. Then, the material was stored in polypropylene plastic bags (Uline Poly Bags, S-1255) at room temperature (21 °C) for further analysis.

During extrusion, parameters including torque, temperature and pressure were recorded. Extrusion rate was determined by collecting the extrudates for 1 min, and weighing the material to determine the mass extruded per minute. Specific mechanical energy (SME), the mechanical energy input per unit mass of the extrudate, was calculated by dividing the net power input to the screw by the extrudate flow rate according to Eq. (1). Specific mechanical energy (Kirby, Ollett, Parker, & Smith, 1988).

$$\mathrm{SME\,(Wh/kg)} = \frac{\text{screw speed (radians/s)} \times \text{torque (N m)}}{\text{Mass flow rate (kg/h)}} \qquad (1)$$

2.3.3. Analyses of the extruded products

2.3.3.1. Expansion ratio.
The diameter of 20 pieces of extruded products was measured using a caliper (Mitutoyo, Tokyo, Japan) and the expansion ratio was calculated by dividing the average diameter of the products by the diameter of the die.

2.3.3.2. Bulk density.
Bulk density (BD) (g/cm^3) of 10 pieces of extrudates was calculated according to Eq. (2) (Bulk density (g/cm^3) Alvarez-Martinez, Kondury, & Karper, 1988), where m is mass (g) of a length L (cm) of extrudate, with diameter d (cm).

$$\mathrm{BD} = \frac{4m}{\Pi d^2 L} \qquad (2)$$

2.3.3.3. Water absorption and solubility indices.
Water absorption index (WAI) and water solubility index (WSI) were determined in triplicate, according to the method of Anderson, Conway, Pfeifer, and Griffin (1969). The WSI was the weight of dry solids in the supernatant reported as percentage of the original weight of sample. The WAI was the weight of gel obtained after removal of the supernatant per unit weight of original dry solids.

2.3.3.4. Colour.
Colour was measured using the method described in Section 2.2.2, using the CIELAB L^*, a^*, b^* colour space. For this analysis the extruded product was ground (Mini Mill, Thomas Wiley, Swedesboro, NJ, USA) and passed through a 40-mesh sieve. Colour readings were taken from 3 separate points on the surface of the powder.

2.3.3.5. Moisture content.
The moisture content of the extrudates was determined in triplicate, according to AACC 44–15A (1999).

2.3.3.6. Texture analysis.
The hardness of the extruded samples was determined by a three-point bend test, using a texture analyser (TMS-PRO, Food Technology Corporation, Sterling, VA, USA), equipped with a TMS lightweight three-point bend probe. Hardness (N) was determined by measuring the maximum force required to break the extruded samples (50 mm long). The probe was set to move at a speed of 0.8 mm/s for a distance of 10 mm and the distance between the two supports was 20 mm. Six measurements were performed for each treatment.

2.4. Experimental design and statistical analysis

The study was a randomized block design, with three blocks (three independent extrusion processes). The statistical analysis was performed according to the set of 14 treatments. The data was subjected to exploratory analysis, to residue analysis, to test of variance homogeneity, to test for outliers and to range of the measured variable. For the texture analysis, a logarithmic transformation (base 10) was performed. The comparison among the means was done with transformed data and the results presented in the original scale. Once the fit of the data was assessed, significant differences among samples were determined by analysis of variance (ANOVA) and Tukey's HSD test ($p < 0.05$), using the software SAS.

3. Results and discussion

3.1. Characterisation of pineapple pomace

3.1.1. Chemical analyses

Moisture and protein content of the freeze-dried pineapple pomace were 3.77 ± 0.52% and 4.71 ± 0.28% (Table 2), respectively. The protein value obtained in this study was similar to the protein content of the pineapple co-product (peel and heart) studied by Martínez et al. (2012) (4%). The pomace had low fat content (0.61 ± 0.14%) (Table 2), which is in agreement with the 0.69% reported by Sousa, Vieira, Silva, and Lima (2011) for pineapple residue obtained from a fruit pulp industry. The present study found higher values of ash (2.24 ± 0.58%) (Table 2) when compared to industrial pineapple residue (0.53%) (Sousa et al., 2011) and lower values compared to pineapple fibre concentrate (4.5%) (Martínez

Table 2
Chemical composition of freeze-dried pineapple pomace (Average ± SD).

Component	Percentage (% db)
Moisture	3.77 ± 0.52
Protein	4.71 ± 0.28
Fat	0.61 ± 0.14
Ash	2.24 ± 0.58
Total dietary fiber	45.22 ± 3.62
Insoluble dietary fiber	44.44 ± 3.60
Soluble dietary fiber	0.78 ± 0.10
Carbohydrates[*]	43.46

db, dry basis.
[*] By difference.

et al., 2012). Differences in fruit variety can influence the content of ash, but, according to Lombardi-Boccia, Lucarini, Lanzi, Aguzzi, and Cappelloni (2004), the main factor influencing mineral concentration in vegetable products is the type of soil used for cultivation. According to the proximate composition, the major compound of the pineapple pomace was fibre (45.22 ± 3.62%), where 98.28% of it was the insoluble fraction (Table 2). This result is in agreement with those reported by Huang, Chow, and Fang (2011), who found 42.2% of total dietary fibre in pineapple peels, with the insoluble fraction being its main constituent (86.02%). However, Larrauri et al. (1997), studying pineapple shell, found 70.61% of total dietary fibre with 99.28% of it being insoluble fibre. Differences in fibre content can also be attributed to differences in cultivars and growing conditions (Figuerola, Hurtado, Estévez, Chiffelle, & Asenjo, 2005). The carbohydrate content in this study was obtained by difference and it is similar of that reported by Huang et al. (2011), who found 42.3% in pineapple peel.

Thus, according to the proximate composition, pineapple pomace can be a promising ingredient for fibre enrichment, leading to the development of healthier products.

3.1.2. Physicochemical analyses

The pineapple pomace had a pH of 3.86 ± 0.07 (Table 3), which is similar to the pH of Gold pineapple (3.77) (Ramsaroop & Saulo, 2007), variety used in this study to obtain the pomace. The water activity of the samples averaged 0.14 ± 0.06 (Table 3) which is lower than those reported by Prakongpan, Nitithamyong, and Luangpituksa (2002) who found 0.24 for pineapple core dietary fibre and 0.28 for pineapple core cellulose. Considering the low pH and water activity of the material evaluated in this study, it has low risk of food deterioration by microorganisms, enzymes or nonezymatic reactions.

Titratable acidity was quantified at 2.01 ± 0.23 g citric acid/ 100 g sample (Table 3). Costa, Felipe, Maia, Brasil, and Hernandez (2007) found 2.53% and 2.98% of citric acid in pineapple peel and pineapple pomace, respectively, values slightly higher than reported here. As most fruits mature, the acidity decreases, and the sugar content increases. Therefore, differences between acidity values may have been caused by variations in fruit ripeness and/or differences in pineapple varieties.

Processed and dried pomace was light in colour, i.e., high L^* value (75.63 ± 3.07) (Table 3), which is a desirable attribute because ingredients with dark colours could limit potential food applications. Regarding the a^* and b^* colour parameters, the sample presented values of −0.1 ± 1.79 and 26.91 ± 2.35, respectively.

3.1.3. Functional properties

The pineapple pomace showed a WHC value of 5.32 ± 0.67 g water/g sample (Table 3), which is lower than the

values reported by Prakongpan et al. (2002), using a similar method for WHC, for pineapple dietary fibre (10.30–12.16 g water/g sample). Differences between reported values more likely were due to differences in the material used for such analysis, since the study of Prakongpan et al. (2002) evaluated dietary fibre extracted from pineapple pomace, as opposed to the pomace itself. Moreover, the hydration properties could be affected by the chemical structure of the polysaccharides present in the material, and other factors such as porosity, particle size, ionic form, pH, temperature, ionic strength and type of ions in solution (Elleuch et al., 2011). When comparing the WHC value of pineapple pomace reported here with other fruit byproducts, it is higher than lemon peel (1.74–1.85 g water/g sample), orange peel (1.65 g water/ g sample) and apple pomace (1.62–1.87 g water/g sample) (Figuerola et al., 2005); and lower than peach pomace (9.2–12.1 g water/g sample) (Grigelmo-Miguel, Gorinstein, & Martín-Belloso, 1999). Besides the plant species, these differences could be due to differences among processing methods. Therefore, because the pineapple pomace as described here has the capacity of holding 5.32 g of its own weight in water, it suggests that it can be used as a functional ingredient in products that require hydration, to avoid syneresis, improve yield, and modify texture and viscosity (Elleuch et al., 2011).

The pineapple pomace showed an OHC of 2.01 ± 0.23 g oil/ g sample (Table 3). Huang et al. (2011) reported the OHC of the insoluble dietary fibre fraction of pineapple peel to be 5.84 g oil/ g sample. This characteristic is a function of the surface properties, overall charge density, thickness, hydrophobic nature of the fibre particle (Figuerola et al., 2005). When compared to other fruits, the OHC results found here for pineapple pomace are higher than the values of peach pomace (1.02–1.11 g oil/g sample) (Grigelmo-Miguel et al., 1999) and lower than pomegranate bagasse (5.9 g oil/g sample) (Viuda-Martos et al., 2012) and lemon by-product (6.58–6.81 g oil/g sample) (Lario et al., 2004). According to Kuntz (1994), ingredients with a high OHC allow the stabilization of high fat food products and emulsions. Due to the low OHC values, pineapple pomace does not present potential to be a used as an ingredient for these purposes.

3.1.4. Microbiological analyses

According to Brackett and Splittstoesser (2001), frozen fruits and vegetables have aerobic plate counts (APC) below 5×10^4 CFU/g. The result found in this study for APC (5.6×10^3 CFU/g) is within the range indicated by these authors. Brackett and Splittstoesser (2001) also reported that coliforms and enterococci are part of the normal flora of plant products, and populations of 10^2 or 10^3 CFU/g of processed products are not uncommon. The present study showed counts of <10 CFU/g for thermotolerant coliform and *E. coli*. Yeast and mold counts in the pineapple pomace were 1.1×10^5 CFU/g and 2.9×10^4 CFU/g, respectively. Low pH and acidity of many fruits are the main factors that influence the composition of their microflora, and, as most yeasts and molds grow well under acid conditions, fungi are often the predominant microorganisms in fruit products. On the other hand, the acidity of fruits is an obstacle for the growth of the more common foodborne pathogens, such as *Salmonella* and *Shigella*, which do not survive in low-pH environment (Brackett and Splittstoesser 2001). The absence of *Salmonella* spp. in PP is in agreement with that.

3.2. Extrusion experiments

The treatments where fibre was added along with 14% of moisture led the extruder to unstable flow and blockage, which made impossible to obtain samples for those conditions. This may have happened because the pineapple pomace has high amount of fibre,

Table 3
Physicochemical composition and functional properties of freeze-dried pineapple pomace (Average ± SD).

Physicochemical parameters	Pineapple pomace
pH	3.86 ± 0.07
Titratable acidity (g citric acid/100 g)	2.01 ± 0.23
Aw	0.14 ± 0.06
Colour	
L^*	75.63 ± 3.07
a^*	−0.10 ± 1.79
b^*	26.91 ± 2.35
Functional properties	
WHC (g water/g sample)	5.32 ± 0.67
OHC (g oil/g sample)	2.10 ± 0.17

WHC, water holding capacity; OHC, oil holding capacity.

Table 4
Extrusion parameters of the extruded products.

PP (%)	Moisture (%)	Temperature (°C)[*]	Torque (Nm)	Pressure (psi)	Extrusion rate (g/min)	SME (W h/kg)
0	14	140	41.43	1.397.87	73.77	214.89
	15	140	39.93	1.346.40	75.58	201.79
	16	140	37.00	1.203.73	75.58	188.06
	14	160	37.90	1.046.83	75.39	192.99
	15	160	34.10	959.73	7170	182.30
	16	160	29.82	850.02	71.92	158.21
10.5	15	140	26.33	1.010.96	63.12	155.01
	16	140	24.77	885.25	56.58	175.95
	15	160	21.63	735.60	57.85	139.11
	16	160	22.13	609.20	45.73	186.85
21	15	140	20.15	884.90	56.86	134.80
	16	140	20.47	809.70	51.08	142.40
	15	160	17.90	584.73	48.92	133.03
	16	160	19.37	512.15	53.38	134.91

[*] Barrel – third zone temperature.

which has as one of its functional properties the capacity to absorb water, preventing the corn starch from being hydrated. This could have resulted in a low level of gelatinized starch, due to insufficient water for gelatinization (Lue, Hsieh, & Huff, 1991). According to Mościcki and Wójtowicz (2011), in extrusion-cooking, mixtures with low water content and high viscosity can overheat and adhere to the cylinder walls or screw, leading to extruder jamming. Thereby, in this study only the results for 14% of moisture and no fibre will be presented and considered as the control for the extrusion, since at this moisture content, extrudates were produced with better quality (expansion, air bubbles formation and visual appearance), when compared to those extruded at 15% and 16% of moisture and no fibre.

3.2.1. Process conditions

All the process conditions used during extrusion, all parameters measured during extrusion runs, the extrusion rates and the specific mechanical energy (SME) calculated are presented in Table 4.

In general, the values of pressure, torque, extrusion rate and SME decreased with the increase of temperature. Viscosity is temperature-dependent, since as the mixture gets cooler viscosity increases (Karkle, Keller, Dogan, & Alavi, 2012). Therefore, an increase in temperature causes a reduction in product viscosity, requiring less torque, which leads to reduced SME and less pressure (Chang, Martinez-Bustos, Park, & Kokini, 1999). When the pineapple pomace was added to the product, all those parameters also decreased with the level of addition. This could have happened due to the presence of sugar in the pomace, since according to Karkle et al. (2012), low molecular weight carbohydrates can reduce the melt viscosity, acting as plasticizers. The increase in moisture content caused a decrease in torque and SME for all treatments with no fibre added, which was expected because water also acts as a plasticizer, reducing melt viscosity and promoting a lower starch gelatinization (Ilo, Tomschik, Berghofer, & Mundigler, 1996). However, for the treatments with added fibre, in general these two parameters increased with an increase in feed moisture content. Fibres and sugars have the capacity of absorb water, reducing its use for corn starch hydration, which probably promoted higher viscosity, consequently requiring more mechanical energy input to the process.

3.2.2. Analyses of the extruded product

3.2.2.1. Expansion ratio.
In general, the treatments where pineapple pomace was added to the mixture, the results showed significant ($p \leqslant 0.05$) reduction in the expansion ratio when compared to the control. This reduction ranged from 8.03% to 37.56% (Table 5). The differences in the expansion can be visually observed in Fig. 1.

The addition of pomace reduced the relative amount of the other components of the mixture when compared with extrusion in the absence of byproduct. According to Bullerman et al. (2008), relative reductions in the amount of starch and protein, mainly responsible for the puffiness of the final product, had a direct impact in the expansion ratio of extruded corn product. Furthermore, this result may also have been influenced by the presence of fibres, which tend to rupture the cell walls before the gas bubbles may expanded to their full potential (Lue et al., 1991). Decreasing in the expansion ratio by the addition of products rich in fibre was also observed in studies done by Altan et al. (2008) and Dehghan-Shoar, Hardacre, and Brennan (2010).

Among the treatments with the same percentage of PP, there was no significant effect ($p \geqslant 0.05$) of the temperature and the moisture in the expansion of the extrudates.

3.2.2.2. Bulk density.
Addition of 21% of pineapple pomace in the blends significantly increased ($p \leqslant 0.05$) the bulk density of the extrudates when compared with the control (Table 5). This result could be explained by the amount of fibre and sugar present in the PP. According to Dehghan-Shoar et al. (2010), these compounds have the capacity to absorb water, which can lead to products with increased density. Also, with the reduction in expansion of extrudates with fibre addition, an increase in density was expected, since more products could be compacted in a given volume. Similar effects were observed during extrusion with orange peel, grape peel, and tomato pomace (Yağcı & Göğüş, 2008). However, the lowest level of pomace addition (10.5%) did not affect ($p \geqslant 0.05$) the product density when compared to the control.

3.2.2.3. Water absorption index (WAI) and water solubility index (WSI).
Water absorption index measures the amount of water absorbed by starch and can be used as an index of gelatinization (Anderson et al., 1969). The WAI for treatments without and with pomace ranged from 5.53 ± 1.29 to 7.11 ± 0.66 g gel/g and from 6.01 ± 0.08 to 6.90 ± 0.13 g gel/g (Table 5), respectively, with no significant differences ($p \geqslant 0.05$) among them. The lack of difference could be explained by higher starch content in treatments without fibre addition, which swell when heated in excess water; while treatments had the fibre rich pineapple pomace, which also has the property of holding water.

When treatments without fibre addition were compared, the one with 14% of moisture and extruded at 140 °C showed the lowest WAI (5.53 ± 1.29 g gel/g), while the one with the highest moisture (16%) and temperature (160 °C) presented the highest value (7.11 ± 0.66 g gel/g). Water absorption index has been reported to be influenced by factors such as temperature and moisture.

Table 5
Effects of the treatments on the characteristics of the extrudates.

PP (%)	Temperature (°C)	Feed moisture (%)	Expansion ratio (%)	Bulk density (g/cm³)	WAI (g gel/g)	WSI (%)	Colour			Extrudate moisture (%)	Hardness[h] (N)
							L^*	a^*	b^*		
0	140	14	3.86 ± 0.27^{ab}	0.10 ± 0.01^{ef}	5.53 ± 1.29^{b}	40.41 ± 10.12^{b}	81.07 ± 2.03^{ab}	0.99 ± 1.62^{bcd}	44.53 ± 1.82^{bcdef}	2.82 ± 0.27^{bcd}	7.15 ± 0.64^{a}
0	140	15	3.87 ± 0.23^{ab}	0.12 ± 0.01^{def}	5.85 ± 0.56^{ab}	36.50 ± 4.82^{ab}	83.51 ± 1.09^{a}	−0.21 ± 0.58^{cd}	45.83 ± 0.35^{bcde}	3.06 ± 0.07^{bc}	8.05 ± 1.54^{a}
0	140	16	3.84 ± 0.15^{ab}	0.14 ± 0.01^{cde}	6.92 ± 0.11^{ab}	27.99 ± 1.01^{bcd}	85.43 ± 0.32^{d}	−1.56 ± 0.32^{d}	49.14 ± 1.33^{ab}	3.91 ± 0.06^{a}	7.75 ± 1.13^{a}
0	160	14	4.06 ± 0.07^{a}	0.08 ± 0.01^{f}	6.31 ± 0.97^{ab}	33.89 ± 8.69^{abc}	81.74 ± 0.43^{ab}	0.49 ± 0.22^{bcd}	46.56 ± 2.44^{abcd}	2.76 ± 0.20^{bcd}	7.61 ± 1.42^{a}
0	160	15	3.98 ± 0.03^{ab}	0.10 ± 0.01^{ef}	6.81 ± 0.11^{ab}	29.27 ± 2.11^{abcd}	83.34 ± 0.87^{a}	−0.09 ± 0.51^{dc}	46.83 ± 1.15^{abc}	2.93 ± 0.26^{bc}	7.55 ± 0.14^{a}
0	160	16	3.73 ± 0.18^{ab}	0.11 ± 0.02^{def}	7.11 ± 0.66^{a}	25.67 ± 4.40^{bcd}	85.22 ± 0.29^{a}	−1.05 ± 0.44^{d}	51.35 ± 0.54^{a}	3.30 ± 0.19^{ab}	7.40 ± 0.99^{a}
10.5	140	15	3.34 ± 0.22^{cd}	0.13 ± 0.01^{cde}	6.66 ± 0.44^{ab}	28.28 ± 4.99^{bcd}	69.14 ± 4.31^{c}	5.88 ± 2.64^{a}	42.54 ± 0.88^{cdef}	2.60 ± 0.31^{cd}	5.51 ± 0.83^{a}
10.5	140	16	3.55 ± 0.10^{bcd}	0.12 ± 0.02^{def}	6.78 ± 0.21^{ab}	24.86 ± 2.22^{cd}	70.69 ± 7.0^{c}	3.79 ± 2.95^{ab}	41.72 ± 4.57^{def}	3.04 ± 0.44^{bc}	7.13 ± 1.79^{a}
10.5	160	15	3.16 ± 0.14^{de}	0.13 ± 0.01^{cde}	6.83 ± 0.03^{ab}	22.53 ± 1.67^{d}	74.52 ± 2.48^{bc}	3.61 ± 1.73^{abc}	43.34 ± 1.36^{cdef}	2.64 ± 0.31^{cd}	5.99 ± 1.28^{a}
10.5	160	16	3.14 ± 0.13^{def}	0.13 ± 0.01^{cde}	6.90 ± 0.13^{ab}	23.14 ± 2.99^{cd}	74.13 ± 1.73^{bc}	2.95 ± 1.18^{abc}	43.52 ± 1.41^{cdef}	2.82 ± 0.09^{bcd}	7.20 ± 1.26^{a}
21	140	15	2.76 ± 0.23^{efg}	0.15 ± 0.00^{bcd}	6.09 ± 0.04^{ab}	26.59 ± 0.74^{bcd}	68.10 ± 6.87^{d}	5.02 ± 2.25^{a}	40.11 ± 3.60^{f}	2.26 ± 0.07^{d}	6.09 ± 0.23^{a}
21	140	16	2.72 ± 0.10^{fg}	0.19 ± 0.01^{a}	6.27 ± 0.07^{ab}	22.85 ± 1.29^{d}	70.12 ± 2.66^{c}	3.98 ± 1.48^{ab}	41.06 ± 1.06^{ef}	2.93 ± 0.13^{bc}	6.17 ± 0.43^{a}
21	160	15	2.41 ± 0.09^{g}	0.16 ± 0.02^{abc}	6.01 ± 0.08^{ab}	22.63 ± 0.96^{cd}	70.12 ± 3.69^{c}	4.93 ± 2.03^{a}	41.20 ± 2.32^{ef}	2.24 ± 0.35^{a}	5.76 ± 0.51^{a}
21	160	16	2.48 ± 0.06^{g}	0.19 ± 0.02^{ab}	6.01 ± 0.11^{ab}	21.94 ± 1.02^{d}	70.68 ± 1.88^{c}	3.97 ± 1.23^{ab}	39.64 ± 1.90^{f}	2.44 ± 0.10^{cd}	5.71 ± 0.81^{a}

Averages followed by different letters are significantly different ($p < 0.05$) by Tukey's HSD test.

[h] Data with logarithmic transformation (base 10). The comparison among the means was performed with transformed data and the results presented in the original scale.

Limited water (14% moisture) could have caused more polymer damage during extrusion, resulting in low WAI. Also, according to Mercier and Feillet (1975), WAI generally increases along with the increase in extrusion temperature until certain point (temperature peak), after which it decreases, probably due to increased dextrinization. Since in this study the increase in extrusion temperature of treatments without fibre caused only an increase in the water absorption of the extrudates, no maximum WAI peak was observed in the temperature range used in this study.

Water solubility index measures the amount of soluble components released during extrusion (Kirby et al., 1988). It is often used as an indicator of the starch degradation (dextrinization) (Ding, Ainsworth, Plunkett, Tucker, & Marson, 2006), since this process leads to the generation of smaller and more water soluble molecules. Besides changes in starch, WSI may also be influenced by structural changes of other components during extrusion, such as proteins, which undergo denaturation, affecting its solubility, and fibres. According to Brennan et al. (2013a) the water solubility of dietary fibre can be increased during extrusion, indicating a potential role of this process in altering its molecular structure. However, when the WSI was evaluated, the presence of PP at both levels tested caused less solubilisation of the matrix components during extrusion when compared to the control (Table 5). This decrease in WSI may have occurred due to the fibre content of the material (45.2 ± 3.62%), which has 98.3% of it as water insoluble fraction, along with the fact that these treatments have less amount of starch in their composition, which, during extrusion, would lead to the release of more soluble compounds. A decrease in WSI with an increase in fibre was also observed by Kumar et al. (2010), who used carrot pomace.

In the treatments without pomace, there was no significant difference ($p \geqslant 0.05$) in the WSI between the products extruded at 14% and 15% of moisture. However, a reduction in the WSI was observed for products extruded at 16% when compared to the control (14% moisture). According to Gomez and Aguilera (1983), the process of dextrinization is well known as the predominant mechanism of starch degradation during low moisture extrusion. Therefore, it was expected that extrusions done with lower moisture would lead to extruded products with higher WSI as a consequence of a greater intensity of dextrinization (Table 5).

3.2.2.4. Colour. Extruded products with added PP did not present any colour differences among them, but, in general, they showed a darker colour ($p \leqslant 0.05$) than treatments without pomace. This reduction in lightness may have been caused by the presence of PP in the final product and also due to browning reactions, such as Maillard and caramelization, promoted by the presence of sugar in the added material. Similarly, Dehgahn-Shoar et al. (2010) observed reduction in lightness of extruded products when working with tomato skin.

Three of the four treatments where PP was added and the blend moisture content adjusted to 15%, presented higher a^* values ($p \leqslant 0.05$) when compared with the control (Table 5). The increase in redness may have been caused by browning reactions due to processing temperatures and presence of sugars in the pomace. Specifically for the treatments with 15% of moisture, this effect could have been enhanced, because Maillard reaction is favored by low moisture. Similar results were observed by Yağcı and Göğüş (2009), who verified that an increase in moisture content generally decreased the redness of the final products.

The use of pineapple pomace did not affect ($p \geqslant 0.05$) the yellowness (b^* value) of the extrudates (Table 5), when results were compared to the control.

3.2.2.5. Moisture content. There was no significant difference ($p \geqslant 0.05$) among the moisture content of the treatments with PP
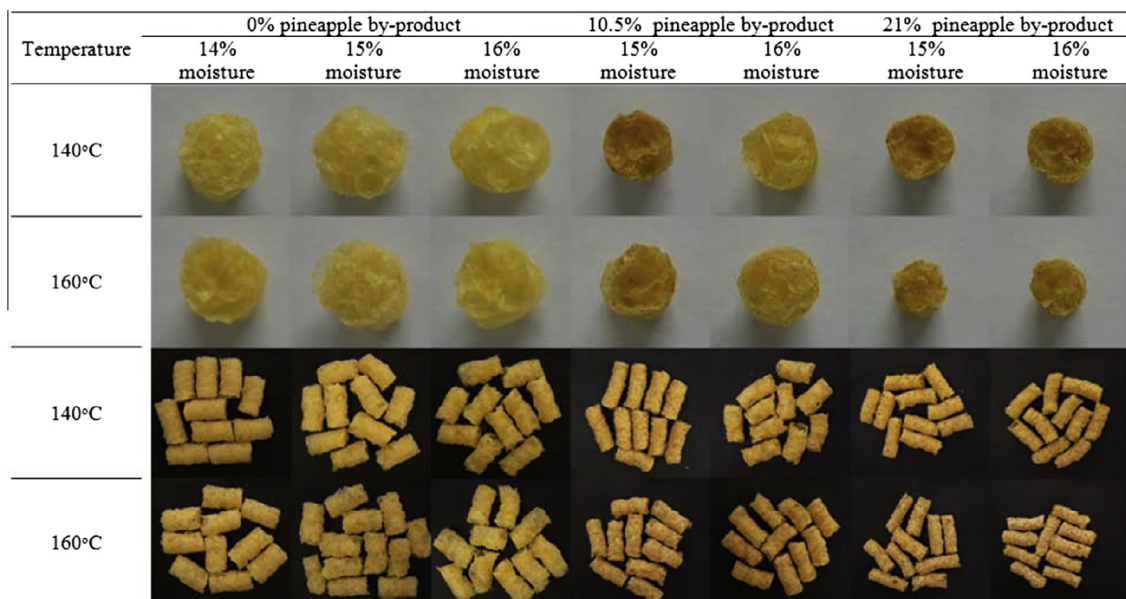
Fig. 1. Appearance of the extruded products.

addition and the control, indicating that the drying step after extrusion (100 °C/10 min) probably homogenised the moisture content of the extruded products (Table 5). These results are important for the purpose of treatments comparison in the texture analysis.

3.2.2.6. Texture analysis. There was no difference ($p \geqslant 0.05$) in hardness among treatments with and without pineapple pomace, indicating that the amount of fibre added did not affect the texture of the extruded product (Table 5). This result is in agreement with those reported by Stojceska et al. (2008), who verified that the hardness of extruded products was not related to the level of addition of cauliflower byproduct. In contrast, the study of Altan et al. (2008) showed that increasing grape pomace level resulted in an increase in the hardness of extrudates. In the present study, when extrudates obtained with the same amount of fibre but at different moisture blends and extrusion temperatures were compared, no effect ($p \geqslant 0.05$) of these parameters were observed in the hardness of the product.

4. Conclusions

The pineapple pomace showed low fat and protein content and had dietary fibre as one of its major components ($45.22 \pm 3.62\%$), with the insoluble fraction accounting for the majority of the fibre. Low microbiological counts, water activity, titratable acidity and pH indicated the good microbiological quality of the material and its low risk for physicochemical deterioration. The measured colour showed high L^* values, which can be a positive attribute, since dark colour may limit the application of this byproduct in foods. The pineapple pomace showed low OHC but considerable WHC, suggesting that this ingredient could be used in products that require hydration, to improve yield, and modify texture and viscosity.

Extruded products added with 10.5% and 21% of PP expanded less and were darker than the control. In general, treatments with the same amount of PP were not affected by extrusion moisture and barrel temperature. Bulk density, hardness, WAI, and b^* value of the products added with 10.5% of PP were not different than the control, showing satisfactory results related to the properties and

characteristics of extruded products, which opens the possibility of a new application for this fruit pomace.

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