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Orange-fleshed sweet potato flour as a precursor of aroma and color of sourdough panettones

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A R T I C L E I N F O

Keywords:
Ipomoea batatas
Long fermentation
Aroma*Chemical compounds studied in this article:*
Acetic acid (PubChem CID 176)
Nonanal (PubChem CID 31289)
Ethyl octanoate (PubChem CID 7799)
2,4-Decadienal (trans, trans) (PubChem CID 24901481)
Butylated hydroxytoluene (PubChem CID 31404)
Dimethyl-decane (PubChem CID
2-Octenal (PubChem CID 5283324)
Decanal (PubChem CID 8175)
Tetradecane (PubChem CID 12389)
Ethyl hexadecanoate (PubChem CID 12366)
2-Octenal-2-butyl (PubChem CID 5352696)
Dimethyl-decane (PubChem CID 28459) and 2-Chloro-octane (PubChem CID 12347)

A B S T R A C T

The nutrients and the color profile of orange-fleshed sweet potato flour (SPF) can contribute positively with the long fermentation products. This study aimed to evaluate the effect of the substitution wheat flour (WF) by SPF in the sponge and dough phases on the quality (moisture and color) and flavor profile of sourdough panettone. Panettone was obtained using spontaneous sourdough and long fermentation time (23 h). Four formulations were made, as follows: AP1 (control), AP2 (10 g/100 g SPF in dough phase or last fermentation), BP3 (10 g/100 g of SPF in sponge phase or intermediary fermentation), and BP4 (10 g/100 g SPF in each phase, sponge and dough phase). The formulation BP4 had a more moist crumb, a high yellow color intensity, and a smaller specific volume (3.26 cm^3/g) when compared to the control (3.76 cm^3/g). Regarding the volatile compounds, three compounds were identified in the panettones made with SPF: 2-octenal-2-butyl, dimethyl-decane, and 2-chlorooctane, which were not found in control. These results can contribute to further studies about the use of SPF as a precursor of new flavor compounds in long fermentation times bakery products, thus reducing or eliminating the use of aromatic additives and food colorings.

1. Introduction

In recent years, the number of studies using sweet potato (*Ipomoea batatas* L.) has increased, due to its nutrients and the presence of antioxidant compounds, besides its interesting color, flavor, and aromas, with potential as a natural enhancer of these attributes (Nogueira et al., 2018).

Sweet potato is rich in carbohydrates, minerals, and vitamins, in addition to amino acids, such as aspartic and glutamic acid and proline, and antioxidant compounds such as phenolic acids, anthocyanins, tocopherol and β-carotene (Iwe, van Zuilichem, Ngoddy, & Lammers, 2001), which can vary according to the sweet potato variety (Steed & Truong, 2008). With respect to the carbohydrates, sweet potato flour contains certain sugars including maltose, sucrose, fructose, glucose, and raffinose and fructooligosaccharides nystose (GF3) and 1-fructofuranosynystose (GF4) (Sancho, Souza, de Lima, & Pastore, 2017), which, even in small amounts, can favor the production of bakery products using long fermentation times, such as panettones.

The rusticity of sweet potato and its nutritional and socioeconomic benefits, its use is still modest (Cardoso et al., 2005). In this way, the use of sweet potato flour can be a viable alternative, resulting in new applications (Bovell-Benjamin, 2007) and favoring the use of tuber-wheat flour blends in non-wheat producing countries.

Besides, in Brazil the postharvest losses continue to be a persistent and relevant problem (Henz, 2017). According to FAO (Food and Agriculture Organization, 2011), the tubers are perishable, which make these products easily damaged during harvest and post-harvest operations, especially in the warm and humid climates of many developing

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countries. Thus, the processing of the tubers in flour is the alternative way for stabilize, add value and enlarge its use, stimulating the local agribusiness.

Panettone is a product with a long shelf-life that can last for months, and its quality is maintained during storage through the addition of various additives, such as oxidizing agents, emulsifiers, enzymes and antifungal (Benejam, Esteffolani & León, 2009), thus the reduction or elimination of additives has been one of the goals of the food industry.

An alternative to the additives is the use of sourdough fermentation, that is the most natural, sustainable and effective features on the bakery products (Gobetti, Corsetti, & Rossi, 1994). The sourdough promotes biochemical changes in the gluten network through the action of lactic acid bacteria (LAB) (Kulp, 2003; Poutanen, Flander, & Katina, 2009). This result in improvements in the rheological, sensory (aroma and flavor) and technological properties, besides increasing the microbiological stability of bakery products provided by organic acids derived from the metabolism of acid-lactic bacteria, such as propionic acid, bacteriocins and other compounds (Kulp, 2003; Gobbetti et al., 1994). In addition, studies have shown that sourdough may also affected nutritional and functional properties, with positive results on the starch digestibility, leading to a lower glycemic response, modulating levels and bioaccessibility of bioactive compounds and improvement of mineral bioavailability (Lattanzi et al., 2013; Ravyts & de Vuyst, 2011).

The use of sourdough for panettone manufacture can lead to improvements in the volatile profile of the products, resulting from enzymatic, fermentative, and thermal reactions occurring during the processing steps. The most common aromatic compounds found when using sourdough are diacetyl, other carbonyls, ethyl acetate, and iso alcohol mainly due to the metabolism of LAB and yeasts (Montanari et al., 2014). The use of orange-fleshed sweet potato flour (SPF) can change the fermentative metabolism of the microorganisms found in sourdough, resulting in a differentiated aromatic profile, besides enhancing the yellow color and improving flavor.

The objective of this study was to evaluate the effect of the addition of SPF to the sourdough and the manufacture of long fermentation panettones, as well as to verify the effect of the addition of SPF on the technological properties, and volatile compounds of the final products.

2. Material and methods

2.1. Material

Orange-fleshed sweet potatoes were purchased at CEASA Campinas (Supply Centers of Campinas S.A.). Wheat flour (WF), suitable for baking quality characteristics (Nita - Moinho Paulista, Santos, Brazil), however was necessary to add the gluten vital content in the formulation. This flour presented 11.02 g/100 g moisture, and the farinographic parameters water absorption, development time, and stability of 56.13 ± 0.23 g/100 g, 13.47 ± 0.76 min, and 18.93 ± 0.15 min, respectively. The alveographic characteristics were: maximum overpressure needed to blow the dough bubble (P) of 87.63 ± 5.46 mm, average abscissa at bubble rupture (L) 71.33 ± 2.31 mm, P/L 1.22 ± 0.07, deformation energy (W), an index of dough strength, 249.26 ± 23.54 10^{-4}J, and Falling Number 405 s. The other ingredients were purchased from companies and markets in the region of Campinas, Brazil.

2.2. Manufacture of orange-fleshed sweet potato flour

The SPF was prepared by freeze-dried according Nogueira et al. (2018). The sweet potatoes were sanitized, peeled, cut (3 cm × 1 cm) and subjected to blanching with hot water until inactivation of peroxidase (100 °C/5 min). After, were packed in low density polyethylene (LDPE) bags, white pigmented with 1.5% titanium dioxide. (Plastunion Indústria de Plásticos Ltda., Caieiras, Brazil), vacuum-sealed and frozen (- 40 °C). The samples were freeze-dried (Liotop LP820, Liobras Comércio e Serviço de Liofilizadores, São Carlos, Brazil) for 24 h, ground using a blender (OBL10/2, Oxy, Santana de Parnaíba, Brazil) until 32 mesh sieve. Thus, the SPF was packed again with the same LDPE material bags and stored at 10 °C until analysis and in panettone addition.

2.3. Characterization of the raw material

Proximate composition: WF and SPF were characterized for proximate composition according to the methodologies of AACCI (2010), as follows: moisture (method 44–15.02); crude fat (method 30–10.01); crude protein (method 46–13.01), and ash (method 08–01.01) and the total carbohydrates content was calculated by difference. All analyses were performed in triplicate.

Instrumental color: the color was measured in triplicate using the Mini Scan XE 45/0-L spectrophotometer (Hunterlab, Reston, United States) according to Nogueira et al., 2018. Total colour difference (TCD) (Equation (1)) indicates the magnitude of color change after treatment.

$$TCD = \sqrt{}(L^*-L_0)^2 + (a^*-a_0)^2 + \sqrt{}(b^*-b_0)^2 \quad (1)$$

where, L_0, a_0 and b_0 are the colour values of wheat flour.

pH and total titratable acidity (TTA) of sourdough and panettone: the determinations were performed according to methodologies 943.02 of AOAC (2010) and 310/IV of the Adolfo Lutz Institute (IAL, 2008) by a pH-meter. All analyses were performed in duplicate with three sub-samples.

2.4. Preparation and characterization of the sourdough microbiota

The initial sourdough was prepared by spontaneous fermentation using WF and water, according to Kulp (2003). The traditional or first sourdough (SD1) was refreshed using sourdough: WF: water ratio of 1.0:0.5:0.5, having a dough yield of 200 (DY = dough weight x 100/flour weight), and incubated at 26 °C. This procedure was repeated once for four days consecutive. The second sourdough (SD2) used the same conditions as traditional sourdough, except the last refreshing was added 10 g/100 g of SPF in substitution to WF.

The sourdough microbial counts were performed according to the Compendium of Methods for the Microbiological Examination of Foods (Downes & Ito, 2001). For the LAB counts, the sourdough was inoculated in MRS culture medium at 30 ± 1 °C for 48 ± 3 h. The analyses were performed in composite sample, that is, the sample comprised two selected sample to represent the material analyzed.

2.5. Panettone manufacture

As shown in Table 1, four different formulations were made with two sponges obtained from SD1 and SD2, as described in Section 2.4, and fermented for 15 h, following the sponge and dough method, according to Kulp (2003), with some modifications. The tests were processed in duplicate. To obtain the sponges, the ingredients of the first step (sourdough, water, WF, gluten vital, egg yolk, enzymes, emulsifier and 58% of sugar) were added to the vertical spiral mixer with two speeds (SRIS/3364, Suprema, Sumaré, Brazil), and subjected to fermentation in a climatic proofer for 3 h at 38 °C and 75–85% RH. The sponges containing some of the ingredients, especially sugar, for sourdough microorganism adaptation.

Subsequently, after the first fermentation, the remaining ingredients were added to the fermented sponge and mixed until gluten network formation. The doughs were divided into 285 g portions, placed in paper forms and incubated at 38 °C and 75–85% RH. The assays AP1 (WF in both phases, sourdough and dough), AP2 (10 g SPF/100 g on the dough phase) and BP1 (10 g SPF/100 g sourdough phase) were fermented for 4 h 40 min, while BP2 (10 g SPF/100 g in both phases, sourdough and dough) was 4 h and 10 min. The fermentation time was

Table 1
Formulations of panettones control (AP1) and with orange-fleshed sweet potato flour (AP2, BP3, BP4).[a]

Ingredients	Step 1 - Sponge[d]	
	Sponge A	Sponge B
Sourdough (SD)[b]		
SD1	30	–
SD2	–	30
Wheat flour[c]	90	90
Water	33	33
Sugar	17	17
Vital gluten	3	3
Alpha-amylase fungal - A500	0.02	0.02
Distilled monoglycerides	2	2
Egg yolks	8	8
DATEM	0.5	0.5
ADA	0.003	0.003
Maltotetraose	0.025	0.025

	Step 2 – Dough[d]			
	Dough AP1	Dough AP2	Dough BP3	Dough BP4
Wheat flour[c]	10	–	10	–
Yellow sweet potato flour[c]	–	10	–	10
Margarine	15	15	15	15
Sugar	12	12	12	12
Salt	0.8	0.8	0.8	0.8
Calcium propionate	0.2	0.2	0.2	0.2
Ascorbic acid	0.008	0.008	0.008	0.008
ADA	0.003	0.003	0.003	0.003

DATEM = Diacetyl tartaric acid ester of mono and diglycerides, ADA = Azodicarbonamide.

[a] -units g/100 g.

[b] - SD1 = 1:0.5:0.5 (sourdough: wheat flour: water); SD2 = 1:0.45:0.05:0.5 (sourdough: wheat flour: orange-fleshed sweet potato flour: water).

[c] -wheat flour or wheat flour and orange-fleshed sweet potato flour basis, when added together the sponge and dough step complete 100%.

[d] - In sponge, the ingredients were calculated in flour basis, in grams.

evaluated as the time at which the mass reached the top of the paper form.

The panettones were baked at 180 °C for 50 min in a ballast oven (Suprema, Curitiba/PR/Brazil), cooled and sprinkled with a sorbic acid solution. Then, the samples were packed in polypropylene bags and stored at a controlled temperature of 20 °C until analysis.

2.6. Physicochemical characterization of panettones

The physicochemical analyses were performed in duplicate with three sub-samples according to the methods described below.

Specific volume: was evaluated according to method 10.05.01 (AACCI, 2010), and calculated by the relation between the volume and the weight of the panettones (cm^3/g).

Crumb color: was determined in the sliced panettones as described in Section 2.2.

Moisture: the samples were prepared according to method 652–05.01 (AACCI, 2010), and the analysis according to method 44–19.01 (AACCI, 2010).

Water activity: was performed in CX-2 AquaLab apparatus (Decagon, Pullman, USA), according to manufacturer's manual.

Instrumental firmness: was determined in TA.XT2i texture meter (Stable Micro Systems, Haslemere, GBR) according to method 74–09.01 (AACCI, 2010) using two slices of 10 mm thick for each replicate. The test conditions were: HDP/90 platform, P/35 aluminum probe, test speed = 1.7 mm/s, 40% compression, and 0.05 N trigger force. The results were expressed in N.

Soluble solids (SS): a Leica AR200 refractometer (Leica Microsystems Inc, Garches, France) was used, according to method 315/IV of the Adolfo Lutz Institute (IAL, 2008).

2.7. Volatile organic compounds (VOCs)

Each 5 g of panettone was placed in a 100 mL vial, sealed with a screw-capped top containing a teflon-lined septum for VOCs headspace solid phase microextraction (HS-SPME) and 20 mL of distilled water was added. SPME extractions were carried from the headspace of the samples, according to the following conditions: PDMS/DVB fiber, equilibrium time of 30 min; extraction time of 30 min and extraction temperature of 50 °C. The volatile compounds were identified on a gas chromatograph coupled to a mass spectrometer, CG-MS (CG 7890A MS 5975C Inert MSD, Agilent Technologies, USA) using an HP-5 fused silica capillary column. The splitless valve was closed for 3 min to compound desorption from the SPME fiber to the GC injector at 240 °C. The oven temperature was programmed starting at 40 °C until reaching 240 °C, at a rate of 4 °C/min. Helium was used as a carrier gas at a flow rate of 1 mL/min. Compounds were identified using NIST 14.0 database. The analyses were performed in duplicate with three sub-samples.

2.8. Statistical analysis

The results were evaluated through analysis of variance and multiple Tukey's comparison test ($p \leq 0.05$) using the software Statistica 7.0 (Statsoft, Tulsa, USA).

3. Results and discussion

3.1. Nutritional and physicochemical characteristics of wheat flour and orange-fleshed sweet potato flour

The proximate composition and the color parameters of WF and SPF are shown in Table 2. The WF composition was similar to those presented by the Brazilian Table of Food Composition (TACO, 2011). The SPF stood out for the carbohydrates content (91.84 g/100 g) and minerals (1.80 g ash/100 g).

Regarding the instrumental color, the orange-fleshed sweet potato was chosen for this study due to its availability in the local market, besides its natural yellow color that was considered adequate for panettone manufacture. According to the results in Table 2, WF is within the standard, being white-cream and clear. The color difference between WF and SPF, was 21.40. Tiwari, Muthukumarappan, O'Donnell, Chenchaiah, and Cullen (2008) classifies analytically the total color difference (TCD) as very distinct (TCD > 3), distinct (1.5 < TCD > 3), and small difference (TCD < 1.5), thus the flours of this study were considered to be very distinct, with SPF considered darker (L* 87.22)

Table 2
Proximate analysis and instrumental color of wheat and orange-fleshed sweet potato flours.

Analysis	Wheat flour	Orange-fleshed potato flour
Proximate analysis (g/100 g)		
Moisture	11.63 ± 0.03	3.12 ± 0.10
Fat	0.98 ± 0.03	0.34 ± 0.02
Protein	11.11 ± 0.06	2.90 ± 0.04
Ash	0.65 ± 0.03	1.80 ± 0.06
Carbohydrates[a]	75.63 ± 0.04	91.84 ± 0.05
Instrumental Color		
L*	97.00 ± 0.04	87.22 ± 0.22
a*	0.71 ± 0.02	2.08 ± 0.02
b*	10.36 ± 0.19	29.34 ± 0.29

[a] - Calculated by difference. Values ± standard deviation of means.

and with a more yellowish hue (b* = 29.43) when compared to WF (L* 97.00 and b* = 10.36). Teow, Truong, McFeeters, Thompson, and Yencho (2007) reported that the natural color of sweet potatoes is due to the presence of antioxidant compounds, such as carotenoids, phenolics, and anthocyanins, which provides the coloring of the varieties of this tuber.

3.2. Sourdough

The sourdough presented a microflora mainly composed of LAB and yeasts, which are derived from the starter culture, being metabolically active or requiring activation (Di Cagno et al., 2002). In recent years, sourdough has been valued for its more natural, healthy, and handmade character, in addition to the differentiated flavors it gives to the products (Komlenić, Slačanac, & Jukić, 2012).

According to Chavan and Chavan (2011), the TTA and the pH of dough are important parameters to control the sourdough fermentation. Arendt, Ryan, and Dal Bello (2007) has stated that most biochemical changes in dough occur through the reduction of pH during fermentation, which promotes greater gas retention and higher resistance of the gluten network, inhibition of flour amylases, water binding of gluten and starch granules, swelling of pentosans, solubilization of the phytate complex by endogenous phytase, and prevention of microbial deterioration.

No significant differences were observed in TTA for sourdough obtained from SD1 and the SPF in SD2 (Table 3). However, the pH increased in SD2, which may have led to higher total yeast counts, without affecting the total LAB counts.

The results of this study are close to the pH and TTA values found in the literature for bread, with values pH of 3.5–4.0 (Ravyts & de Vuyst, 2011; Lattanzi et al., 2013) (Table 3), and TTA of 6.4–10.8 mL NaOH/10 g (Barber, Martinez-Anaya, Baguena, & Torner, 1987). Brasil (2007) consider the TTA as a major quality criterion of sourdoughs, but this value differs for each country or region. Studies on panetones are scarce, mainly relating TTA values as quality standard.

According to Lattanzi et al. (2013), panettones or products made with a richer formulation (mainly sugars, butter, and eggs) requiring one to two fermentation stages due to adaptation and growth of the microbiota in this dough. However, it may result in products with more acidic taste, due to the greater fermentation time. Therefore, it is common to modify the production protocol of the first fermentation step, reducing the activity of LAB.

Table 3 shows the microbial counts of sourdoughs. Higher LAB counts were observed for both sourdoughs when compared to yeast counts, whereas SD1 presented lower yeasts and higher LAB counts when compared to SD2. Ravyts and de Vuyst (2011) studied the differences in acidification and production of aromatic compounds using different strains in the baking fermentation processes, and also found the predominance of LAB.

Table 3
Total titratable acidity (TTA), pH e total count yeast and lactic bacteria of traditional sourdough with 100% wheat flour (SD1) and the second with 90% wheat flour and 10% orange-fleshed sweet potato flour (SD2).

Analysis	SD1	SD2
TTA (mL NaOH 0.1N)	9.03 ± 0.06$^{n.s.}$	9.15 ± 0.23$^{n.s.}$
pH	3.93 ± 0.06^{b}	4.05 ± 0.01^{a}
Total count yeast (log 10^6 CFU g^{-1})	8.7	97.1
Total count lactic acid bacteria (log 10^8 CFU/g^{-1})	3.6	1.1

CFU: colony forming units, n.s.: not significant and means in the same line followed by the same letters are not different at p ≤ 0.05, according Tukey test.

3.3. Processing analysis and physicochemical and technological properties of panettones

The panettones were processed using the same formulation (Table 1) differentiating only for SPF addition, being AP1 the assay control or traditional with WF, and the assays AP2 (SPF addition on the dough phase), BP1 (SPF addition on the sourdough phase) e BP2 (SPF addition on the sourdough and dough phases). This addition not altered the machinability of the dough during the processing, only presented the small reduction in the time fermentation of the assay BP2, that contain more SPF (10 g/100 g in each production phases). It was occurred, probably, due the SPF composition, especially by the higher content in carbohydrates and ash content than WF.

Table 4 shows the results of the physicochemical and technological characterization of panettones.

The moisture content of panettones varied from 26 to 28 g/100 g, with the highest values for the formulation BP4 when compared to the control (AP1) and the other formulations. The difference between BP4 and the other formulations is probably due to the use of SPF in both phases (sponge and dough), which shows that sweet potatoes can contribute to the moisture retention of the product.

A very moist product is desirable in panettones consumer, since it is related to the perception of softness during chewing. Valcárcel-Yamani and Lannes (2013) evaluated the moisture content of nine panettones brands available in the market, and found values ranging from 22.83 to 26.86 g/100 g. The panettones AP1, AP2, and BP3 were close to the maximum value of commercial products, while BP4 showed higher moisture values when compared to the commercial brands.

Small differences were observed for Aw of panettones, which varied from 0.89 to 0.91, indicating that they are products subjected to deterioration by molds. Several authors (Chavan & Chavan, 2011; Komlemic, Slačanac & Jukić, 2012) have reported an antifungal effect provided by metabolites of acid-lactic bacteria (Kulp, 2003; Gobbetti et al., 1994). However, this property was not evaluated in this study, thus the antifungal agent calcium propionate (0.2 g/100 g) and sorbic acid (0.0006 g/100 g) were used in smaller amounts when compared to traditional formulations. Both preservatives are approved by the Brazilian regulation. The first can be used to fulfill its technological function (Brasil, 2007), usually at the concentration of 0.3 g/100 g (flour basis) (Gioia, Ganancio, & Steel, 2017), while the second is added as a preservative, with limited use for up to 0.1 g/100 (flour basis) (Brasil, 2007).

No significant differences were observed between the pH values of the panettones, which were close to the findings of Oliveira & Marinho (2010), with values ranging from 4.21 to 4.8.

Organic acids present in foods can affect the flavor, odor, and color characteristics, as well as the product's stability and quality (Komlenić; Slačanac, & Jukić, 2013). The Brix parameter indicates the content of soluble solids (mainly sugars), and is expressed in ºBrix. As can be seen in Table 4, the panettones presented similar soluble solids contents.

In relation to acidity, the panettones BP3 and BP4 presented higher acidity, indicating that SPF influenced this parameter in the sourdough phase, increasing the pH of the product and increasing the ºBrix/acidity ratio, giving the products lower sensation of acidity and greater sweetness.

In baking products, the color and flavor attributes appear at the end of the cooking step because of the Maillard reaction. However, several other reactions occur during the temperature increase, such as the inactivation of yeasts and enzymes, starch gelatinization, alteration in gluten proteins, and evaporation of water from the superficial layers, which favors the crust formation (Farahnaky & Majzoobi, 2008).

All panettones presented golden yellow-colored crumb, due to the addition of eggs in all formulations, except for BP4, which was darker (lower L*) in relation to the others. Concerning the color coordinate a*, the panettones crumb presented reddish color, with few differences between them, which was not perceptible to the naked eye. The highest

Table 4
Physico-chemical and technological analysis of panettones with wheat flour (AP1) and with wheat and orange-fleshed sweet potato flours blends (AP2, BP3, BP4).[a]

Analysis	AP1	AP2	BP3	BP4
Physico-chemicals				
Moisture (%)	26.23 ± 0.76 [b]	26.83 ± 0.5 [b]	26.68 ± 0.18 [b]	28.43 ± 1.15 [a]
Aw	0.89 ± 0.0021[c]	0.90 ± 0.0013 [b.c]	0.90 ± 0.0011 [a.b]	0.91 ± 0.0075 [a.b]
pH	4.34 ± 0.17 [n.s.]	4.32 ± 0.03 [n.s.]	4.40 ± 0.07 [n.s.]	4.40 ± 0.06 [n.s.]
ºBrix	14.699 ± 0.001 [n.s.]	14.701 ± 0.003 [n.s.]	14.701 ± 0.002 [n.s.]	14.706 ± 0.002 [n.s.]
Acidity (%)	7.03 ± 0.55 [a.b]	7.36 ± 0.41 [a]	6.60 ± 0.74 [a.b]	5.91 ± 0.20 [b]
ºBrix/Acidity	2.09	1.99	2.23	2.49
Technological				
Cor L*	78.66 ± 1.08 [a]	78.18 ± 1.85 [a]	77.98 ± 1.23 [a]	75.19 ± 0.24 [b]
a*	2.47 ± 0.10 [a.b]	2.35 ± 0.10 [b]	2.45 ± 0.24 [a.b]	2.64 ± 0.13 [a]
b*	21.93 ± 0.50 [c]	24.45 ± 1.16 [b]	22.65 ± 0.53 [c]	27.49 ± 0.44 [a]
Specific Volume (cm^3/g)	3.76 ± 0.17 [a]	3.62 ± 0.26 [a.b]	3.71 ± 0.30 [a]	3.26 ± 0.18 [b]
Instrumental Firmness (N)	2.457 ± 0.33 [b]	3.001 ± 0.22 [b]	3.063 ± 0.43 [b]	3.848 ± 0.52 [a]

[a]Means in the same line followed by the same letters are not different at p ≤ 0.05, according Tukey test. Values ± standard deviation of means. AP1 = traditional panettone; AP2: panettone with 10 g/100 g of orange-fleshed sweet potato flours in substitution of wheat flour in the dough phase; BP3: panettone with 10 g/100 g of orange-fleshed sweet potato flours in substitution of wheat flour in the sponge phase; BP4: panettone with 10 g/100 g of orange-fleshed sweet potato flours in substitution of wheat flour in the sponge and dough phases. n.s. = not significative.

b* values were observed for the sample BP4, probably due to its higher SPF content and a higher interaction between the proteins, sugars, and carotenoids during baking.

Baked goods consumers reported the color as a purchase-decisive factor, thus egg yolk or synthetic colorants can be added to the commercial formulations (Valcárcel-Yamani and Lannes, 2013). Therefore, the use of SPF as a source of reducing sugars and carotenoids becomes promising to totally or partially replace the dyes in bakery products, including panettones.

The specific volume, as well as the mass density, indicates the solids/air ratio incorporated into the product (Scanlon & Zghal, 2001), and are considered important quality parameters, once they are correlated with the crumb softness. Significant differences (p ≤ 0.05) were observed in specific volume of the samples AP1 and AP2, made with the same sourdough (traditional), while AP2 and BP3 were similar to the control. The formulation BP4, which differs from the others by the addition of SPF in both sponge and dough phases, had the lowest specific volume.

An important factor influencing the dough development and consequently its specific volume is the vital gluten content, which is responsible for the structure and gas retention in bakery products. Whereas the partial substitution of WF by SPF leads to the dilution of wheat flour gluten, a smaller specific volume was expected in panettones AP2 and BP4.

The instrumental firmness, volume, and structure are important properties of bakery products. The crumb texture is related to the mechanical properties, and certain ingredients such as flour, sugars, fats, emulsifiers, gluten additives, and flour improvers along with moisture and storage can affect the final product (Scanlon & Zghal, 2001).

The panettone BP4 presented the highest firmness when compared to the other formulations (Table 4). As reported by Valcárcel-Yamani and Lannes (2013), nine commercial brands had firmness between 2.17 and 7.55 N, thus all panettones in this study are close to the minimum values found in commercial products.

Therefore, the substitution of wheat flour by sweet potato flour only in the sponge phase and/or dough phase has proven to be viable in the manufacture of panettones for the maintenance of technological characteristics, such as specific volume and softness.

3.4. Volatile compounds

During the sourdough fermentation are produced two categories of flavor compounds, the nonvolatile and volatile compounds. The first compounds are the organic acids produced by homo and hetero-fermentative bacteria, which acidify, decrease pH, and contribute to the aroma. While the second compounds (alcohols, aldehydes, ketones, esters, and sulfur) are obtained during the fermentation by biological and biochemical actions, and occur in multiple-step process of at least 12 h In addition, there is also an influence of the cooking process, which promotes a Maillard reaction and caramelization (Chavan and Chavan, 2011).

Kulp (2003) reported that the products of the Maillard reaction or the thermal degradation and interaction between the intermediate fermentation products and the amino acids play an important role in the product's flavor, mainly as precursors of aroma compounds. According this author, the flavor of bakery products consists of the odor of freshly baked and of flavor components retained in the crust and crumb and perceived organoleptically upon tasting.

The formation of aromatic compounds in bread crumbs is highly influenced by the temperature, time, and type of fermentation (Birch, Petersen, Arneborg, & Hansen, 2013; Ravyts & de Vuyst, 2011). Most of these compounds are derived from the metabolism of yeasts and LAB, including organic acids and carbonyl compounds (Kulp, 2003), alcohols, aldehydes, as well as 2,3-butanedione (diacetyl), 3-hydroxy-2-butanone (acetoin and esters) (Hazelwood, Daran, van Maris, Pronk, & Dickinson, 2008), and other volatile compounds that affect the flavor characteristics.

Thus, the type of flour, the microorganisms, and the fermentation conditions can affect the formation of the aromatic compounds in bakery products, once organic acids from the LAB metabolism lead to the proteolysis of the flour protein, releasing amino acids that are aromatic precursors (Thiele, Gänzle, & Vogel, 2002).

The VOCs of panettones are shown in Table 5. There were no significant differences for the concentrations of acetic acid, 2-pentylfuran, octanoic acid, and 2,4-decadienal (trans, trans). In contrast, higher nonanal concentrations were observed in AP1, followed by AP2, and BP3, which according to Birch et al. (2013), is a compound resulting from the lipid oxidation, while BP4 presented the lowest nonanal level. All these compounds are characteristic of bread aroma.

Acetic acid is the product of the fermentation of bacteria and yeasts, which explains their presence in all formulations. Higher acetic acid levels, when not dissociated, have positive effects on the inhibition of yeast growth and the control of alcoholic fermentation (Sousa et al., 2008).

Furans are formed by the degradation of sugars, despite 2-pentyl furan is considered a compound from the lipid degradation, formed from linoleic acid by singlet oxygen (Min, Yu, Yoo, & St. Martin, 2005). Unsaturated aldehydes, such as 2,4-decadienal, contribute to the characteristic aroma of wheat and rye crumbs (Schieberle, 1996). According to Birch (2013), aldehydes are also formed from lipid

Table 5
Volatile organic compounds of panettones containing different proportions of orange-fleshed sweet potato flour.[a]

Volatile compounds	AP1	AP2	BP3	BP4
Acetic acid	1.19 ± 0.55 n.s.	0.45 ± 0.15 n.s.	1.32 ± 0.87 n.s.	1.09 ± 0.88 n.s.
2-Pentyl-furan	4.91 ± 0.42 n.s.	6.30 ± 0.23 n.s.	6.00 ± 0.90 n.s.	5.86 ± 0.22 n.s.
Nonanal	5.18 ± 0.52 a	4.36 ± 0.80 b	3.74 ± 0.30 b	3.50 ± 0.80 c
Ethyl octanoate	2.06 ± 0.13 n.s.	3.94 ± 1.70 n.s.	2.77 ± 0.45 n.s.	5.05 ± 0.31 n.s.
2,4-Decadienal (trans, trans)	4.26 ± 0.14 n.s.	5.39 ± 0.01 n.s.	4.25 ± 0.26 n.s.	4.54 ± 1.10 n.s.
2,4-Decadienal	23.27 ± 0.67 n.s.	31.71 ± 0.87 n.s.	22.36 ± 2.03 n.s.	24.66 ± 9.50 n.s.
Butilated hydroxytoluene	17.28 ± 0.44	17.44 ± 3.72	14.76 ± 2.58	15.97 ± 1.03
Methoxy-phenyl-oxime	0.83 ± 0.18	n.d.	1.47 ± 0.80	n.d.
Dimethyl-decane	0.96 ± 0.22	n.d.	1.78 ± 0.85	n.d.
2-Octenal	1.23 ± 0.12	1.47 ± 0.22	n.d.	n.d.
Decanal	1.03 ± 0.0	n.d.	n.d.	n.d.
Tetradecane	1.02 ± 0.03	n.d.	1.18 ± 0.00	n.d.
Ethyl hexadecanoate	2.32 ± 0.0	n.d.	n.d.	n.d.
2-Octenal-2-butyl	n.d.	1.25 ± 0.00	1.04 ± 0.19	1.02 ± 0.0
Dimethyl-decane	n.d	n.d	n.d.	2.04 ± 0.0
2-Chloro-octane	n.d.	n.d.	n.d.	1.65 ± 0.0

[a] Volatile compounds expressed as % peak area. The analyses were performed in duplicate with three sub-samples. Mean values in the same line followed by the same line are not different at $p \leq 0.05$, according Tukey test and n.s.: not significative. n.d.: not detected. AP1 = traditional panettone; AP2: panettone with 10 g/100 g of orange-fleshed sweet potato flours in substitution of wheat flour in the dough phase; BP3: panettone with 10 g/100 g of orange-fleshed sweet potato flours in substitution of wheat flour in the sponge phase; BP4: panettone with 10 g/100 g of orange-fleshed sweet potato flours in substitution of wheat flour in the sponge and dough phases.

oxidation, with a strong influence on the flavor of the final bread.

In this study some compounds varied among the panettones. Ethyl hexadecanoate and decanal were found only in AP1, whereas 2-octanal-2-butyl was found in panettones made with SPF, and dimethyl-decane and 2-chloro-octane were found in BP4, which contained SPF in the sponge and dough phases. The presence of three volatile compounds only in panettones made with SPF and the absence of other volatile compounds found in the control sample (AP1) is indicative of changes in aroma formation. Thus, further studies should be performed to verify the possibility of use of SPF as a precursor of differentiated aromas in bakery products.

This can be occurred due the mineral content of SPF, presented by ash content (1.8 g ash/100 g SPF). According to Katina, Sauri, Alakomi, and Mattila-Sandholm (2002) and Kulp (2003), higher ash contents result in a more acidic sourdough, so proteolytic reactions occur with greater intensity, consequently the resultant products are richer in volatiles compounds.

4. Conclusion

This study showed that it was possible to use SPF in panettones made with sourdough, without affecting the machinability, with slight decrease on the time fermentation and influencing the technological characteristics of the products, with positive effects including a higher moisture and strong yellow color of the crumb, and presence of new volatile compounds.

These results are promising for regions with high production of orange-fleshed sweet potatoes and wheat importers, resulting in economic gains with agribusiness stimulus and healthiness, as they provide differentiated color and aroma when compared to panettones made using conventional formulations, which uses flavorings and colorants.

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