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Physicochemical and sensory characterization of sweet potato beers with purple and yellow flesh

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The use of brewing adjuncts can improve the color, aroma, and flavor of beer. Sweet potatoes (*Ipomea batatas*) are rich in bioactive compounds, such as phenolic compounds with antioxidant activity. Thus, this study aimed to develop and characterize physicochemical and sensorial aspects of craft beers brewed with sweet potatoes with purple and yellow flesh. Three beer formulations were prepared: 50% purple-fleshed sweet potato and 50% barley malt, 50% purple plus yellow-fleshed sweet potato and 50% barley malt, and also 50% yellow-fleshed sweet potato and 50% barley malt. The alcohol content of sweet potato beers ranged from 4.5 to 6.0% (v/v). The total phenolic compounds content of sweet potato beers ranged from 110.44 to 160.86 mg/100 mL and the antioxidant activity values of sweet potato beers ranged from 2.38 to 3.22 mM TE/mL by ABTS and 1.17 to 2.56 mM TE/mL by 2,2-diphenyl-1-picrylhydrazyl (DPPH). The sweet potato beers had good sensory acceptance, obtaining scores of 7.0 to 8.2 for the overall impression, with the purple and yellow-fleshed sweet potato beer being preferred by the evaluators. The beers showed high antioxidant activity and concentration of phenolic compounds, showing that sweet potatoes are a promising brewing adjunct to produce craft beers.

Key words: Craft beer, sweet potato, *Ipomea batatas*, antioxidant activity, phenolic compounds, sensory characteristics.

INTRODUCTION

Beer results from the fermentation of malted barley wort, which has undergone a cooking process with the addition of hops, and brewer's yeast (Brazil, 2019a). According to Brazilian legislation (Brazil, 2019a), part of the malt can be replaced by brewing adjuncts, up to a maximum of 45%. If the beer is produced mainly from a wort derived from brewing adjuncts, it must be labeled appropriately, indicating the predominant adjunct (malted or not). In this case, the beer can contain a maximum of 80% brewing adjuncts and a minimum of 20% barley malt, as specified

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by Brazilian regulations (Brasil, 2019b).

Large commercial breweries often use adjuncts such as corn and rice for economic reasons, given that malt is a pricier source of starch. However, the use of brewing adjuncts can enhance the color, aroma, and flavor profiles of the beer (Gasiński et al., 2023; Kumar et al., 2019). In recent years, there has been a great increase in the Brazilian market for consumption and production of craft beer (Carvalho et al., 2018; Costa Jardim et al., 2018). Unlike large commercial breweries, craft beers are mainly produced in microbreweries and can be produced using different types of adjuncts. Unusual additions to the beer are considered interesting for many of the consumers that choose craft beers because they have a variety of flavors and distinct sensory attributes (Carvalho et al., 2018; Costa Jardim et al., 2018; Hayward et al., 2019).

Few studies have incorporated sweet potatoes (*Ipomea batatas*) and potatoes (*Solanum tuberosum*) into beers, and the findings have shown an increase in the concentration of bioactive compounds in the resulting beers (Gasiński et al., 2023; Humia et al., 2020). Sweet potatoes have a high nutritional value and are composed, in dry matter, mainly of carbohydrates (42.4-77.3% starch and 1.9-6.4% fiber) and proteins (1.3-9.5%), having a low-fat content (0.2-3.0%). Additionally, they are rich in bioactive compounds that benefit consumer health, including vitamin B, minerals such as iron, calcium, magnesium and zinc, and phenolic compounds (Alam, 2021; Wang et al., 2016). Phenolic acids and flavonoids are known for their antioxidant properties and are present in sweet potatoes of all flesh colors, and the presence of anthocyanins is exclusive to purple-fleshed sweet potatoes (Alam, 2021; Kurata et al., 2019; Wang et al., 2016).

Brazil holds 16th among the largest sweet-potato producers, with production of 805.4 thousand tons in 2020 (Vendrame and Melo, 2021), making it the leading producer in Latin America. Among the varieties produced in Brazil is the purple-fleshed sweet potato BRS Cotinga, which has a total anthocyanin content of approximately 154 mg/g, comparable to fruits such as blueberries and blackberries (Vendrame et al., 2022). Another extensively grown variety is the Brazlandia sweet potato with purple peel and yellow flesh. In Brazil, there is a predominance of cultivation of sweet potato varieties with white and yellow flesh color, however, the cultivation of purple and orange-fleshed varieties has been growing year after year, due to their nutritional quality and export potential (Cartabiano-Leite et al., 2020; Leal et al., 2021; Zeist et al., 2022).

Thus, this study aimed to develop and characterize physicochemical and sensorial aspects of craft beers brewed with sweet potatoes with purple and yellow flesh, considering the low use as a brewing adjunct of this abundant, accessible, and cost-effective raw material.

MATERIALS AND METHODS

Raw materials used in the production of beers

The following raw materials were used to produce the beers: brewer's yeast *Saccharomyces cerevisiae* Ale US 05 Fermentis® (Marcqen-Baroeul, France), Pilsen, Munich and Vienna malts from Germany and Columbus, Chinook and Cascade hops from United States. The raw materials were purchased in specialized stores. Yellow-fleshed sweet potatoes were purchased from local producers (CEASA, Brasília, DF) and purple-fleshed sweet potatoes were purchased from producers in the city of Piedade (CEASA, São Paulo, SP). In the laboratory, the sweet potatoes were sanitized in a solution containing sodium hypochlorite at a concentration of 150 ppm and washed in running water before use. Subsequently, the sweet potatoes were cooked, peeled, mashed, and utilized in the brewing worts.

Analysis of brewing wort fermentation time

To study the fermentation time of the wort, 6 liters of brewer's wort (consisting of 50% (w/v) yellow sweet potato and 50% (w/v) barley malt prepared as described) and yeast were incubated at 20°C for 8 days. During 1, 2, 3, 4, 5, 6, 7 and 8 days of alcoholic fermentation, aliquots of the fermented worts were analyzed for soluble solids (°Brix), reducing sugars (g/100 mL) and alcohol degree (°GL).

Production of sweet potato beers

To prepare the brewing worts (composed of 50% (w/v) sweet potato and 50% (w/v) barley malt), the mashing process began by adding the ground malt (total of 2.5 kg of malt, 1.5 of kg Pilsen, 0.8 kg of Vienna and 0.2 kg of Munich) and sweet potatoes (2.5 kg) in mineral water (10 L). The mashing process had three stages: 30 min at 50-55°C, 30 min at 60-65°C and 30 min at 70-75°C. After the mashing process, the wort was filtered, and the malt bagasse was washed with 4 L of mineral water. Then, the wort was boiled for 1 h, and during this stage hops were added (15 g after 30 min of boiling and 15 g after 55 min of boiling). After boiling, the wort was cooled to 20°C using an immersion chiller, filtered, and transferred to a fermenter. Hydrated yeast (0.7 g/L) was added to the wort and the alcoholic fermentation process occurred at 20°C for 8 days. The green beer was then transferred to another fermenter and the maturation process occurred at 5°C for 15 days. Finally, the beers were packaged in 600 mL amber glass bottles and for the carbonation process, glucose syrup (1 g/L) and a yeast suspension (0.2 g/L) were added. The bottled beers were sealed and stored at room temperature for 15 days before the analysis. Three beer formulations were prepared: purple-fleshed sweet potato beer (PSP beer), purple and yellow-fleshed sweet potato beer (PYSP beer), and yellow-fleshed sweet potato beer (YSP beer) (Table 1).

Physicochemical analyses of worts and beers

The pH was determined using a Gehaka PG 1800 digital pH meter. The soluble solids content (°Brix) was determined using a Shimadzu refractometer at 20°C. Total acidity was determined by titrating samples with 0.1 N NaOH (AOAC, 2019). Reducing sugars were determined by the 3-5 dinitrosalicylic acid method (Miller, 1959). Total phenolic compounds were determined by the Folin-Denis method (Folin and Denis, 1912). The antioxidant activity was determined by the method of scavenging the DPPH radical (2,2 diphenyl-1-picrylhydrazyl) and the ABTS radical (2,2 -azino-bis-3-

Table 1. Formulations of sweet potato beers.

Raw material	PSP	PYSP	YSP
Barley malt	2.5 kg	2.5 kg	2.5 kg
Sweet potato flesh	2.5 kg purple	1.3 kg purple and 1.2 kg yellow	2.5 kg yelow
Total malt + sweet potato	5 kg	5 kg	5 kg
Columbus hop	10 g	10 g	10 g
Chinook hop	10 g	10 g	10 g
Cascade hop	10 g	10 g	10 g
Total hops	30 g	30 g	30 g
Wort yield	12 L	12 L	12 L

PSP = purple sweet potato beer, PYSP = purple and yellow sweet potato beer, YSP = yellow sweet potato beer.

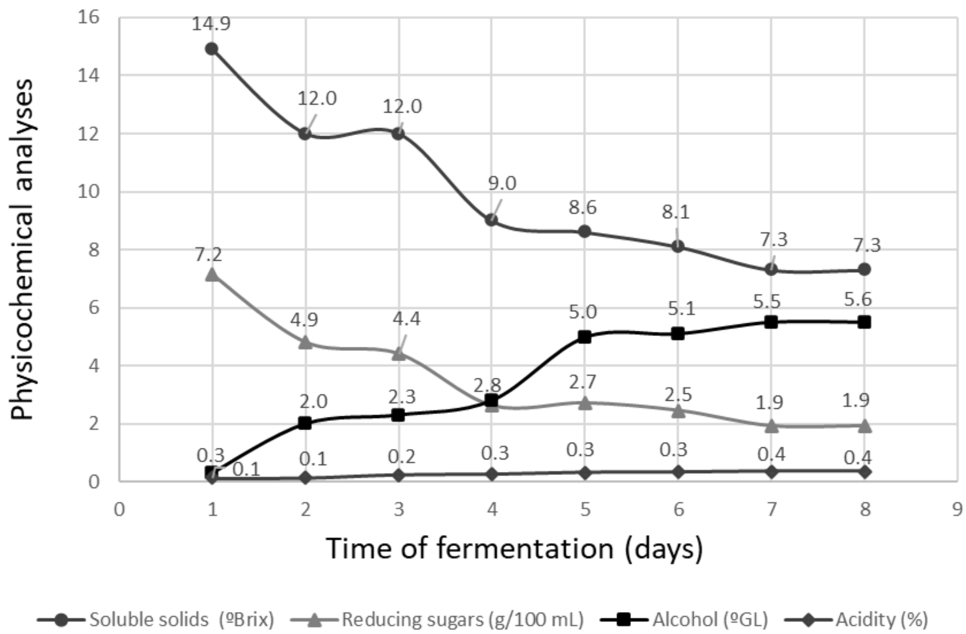

Figure 1. Time-course kinetics of brewing wort fermentation.

ethylbenzo-thiazoline-6-asulfonic acid) (Kim et al., 2002; Re et al., 1999). The results of antioxidant activity were expressed as Trolox equivalents (TE) (mM TE/mL). The alcoholic content of the beers was determined using a Gay-Lussac alcoholometer (°GL or % v/v) placed in a volume of 250 mL of distillate at 20°C (IAL, 2008).

Sensory evaluation of beers

To evaluate the sensory quality of the beers, a trained panel was used with the participation of 15 evaluators (7 men and 8 women, between 21 and 60 years old). The beers were evaluated for the attributes flavor, aroma, color, foam and carbonation and overall impression on a 9-point hedonic scale (1= dislike extremely, 9 = like extremely). Each evaluator was served with 60 mL of beer at a temperature of 8°C, in transparent cups coded with random numbers. Mineral water and salted crackers were also served to clean the palate (IAL, 2008).

Statistical analysis

The data were analyzed using Statistica 10 software (Statsoft, Tulsa, OK, USA) applying one-way ANOVA ($\alpha = 0.05$). The Tukey test was used to analyze differences between means ($p < 0.05$). The means and standard deviation (SD) were used to express the data.

RESULTS AND DISCUSSION

Analysis of brewing wort fermentation time

Figure 1 shows the profiles of soluble solids, reducing sugars, alcoholic content, and acidity during the fermentation time of brewing wort.

A gradual reduction in the soluble solids and sugars

Table 2. Physicochemical analyzes of brewing worts.

Analyses	Worts		
	PSP	PYSP	YSP
Acidity (%)	0.21 ± 0.01^{a}	0.19 ± 0.00^{a}	0.20 ± 0.00^{a}
pH	5.94 ± 0.00^{a}	5.94 ± 0.00^{a}	5.88 ± 0.03^{a}
Soluble solids (ºBrix)	11.00 ± 0.00^{a}	15.00 ± 0.00^{b}	15.00 ± 0.00^{b}
Reducing sugars (g/100 mL)	4.99 ± 0.28^{a}	6.25 ± 0.67^{b}	6.49 ± 0.05^{b}
Phenolic compounds (mg/100 mL)	187.02 ± 1.66^{a}	93.37 ± 5.57^{b}	90.85 ± 1.33^{b}

PSP = purple sweet potato wort, PYSP = purple and yellow sweet potato wort, YSP = yellow sweet potato wort. Data are represented as mean ± SD. Different superscript letters in the same row indicate significant differences ($p < 0.05$)

content was observed from 14.9°Brix and 7.14 g/100 mL on the first day of fermentation to 7.3°Brix and 1.93 g/100 mL in 7-8 days of fermentation. Consequently, there was a gradual increase in alcohol content from 0.3°GL on the first day of fermentation to 5.5-5.6°GL in 7-8 days of fermentation. And an increase in acidity was observed from 0.1% on the first day of fermentation to 0.4% in 7-8 days of fermentation, resulting from the production of organic acids by yeasts during the alcoholic fermentation process (Brito Júnior et al., 2022).

Brito Júnior et al. (2022) reported a faster fermentation process for beers with addition of juçara fruit pulp. A significant reduction in the initial soluble solids content of 12°Brix was observed, and after 3 days of fermentation, the values were below 7°Brix, with no significant variation until the end of the evaluated period (10 days). A decrease in pH from 5.2-5.6 to 4.3-4.8 was observed during fermentation. Capece et al. (2021) reported that for Pilsner and Weizen beers, the alcoholic fermentation finished in 10 days.

It was important to study the fermentation time of the brewer's wort, considering that the incorporation of 50% sweet potato, a non-malted adjunct, could alter the fermentation time of the beers. According to Kumar et al. (2019) using a large amount of adjunct in brewing can reduce the nutrient levels available to the yeast during fermentation, which results in slower fermentation. For the production of Ale-type beers, the standard fermentation time for the wort is 5 to 10 days (Dylan and Pilarski, 2020).

Physicochemical analyzes of brewing worts and sweet potato beers

Table 2 presents the physicochemical analyzes of the brewing worts. The worts had an acidity of 0.10-0.20% and a pH of 5.88-5.94. The pH of the worts was comparable to that of cereal-based beers; thus, the addition of sweet potatoes did not contribute to an increase in wort acidity. In general, the pH of malted barley wort ranges from 4.60–5.80 (Saarni et al., 2020). Gugino et al. (2024) obtained a pH of 6.09-6.34 in wheat malt worts, and Gasinski et al. (2021) achieved a pH of 5.60-5.80 in barley malt worts. On the other hand, the addition of other adjuncts, such as fruits with high acidity, can lead to an increase in wort acidity. Cioch-Skoneczny et al. (2023) observed an increase in wort acidity from 1.16 to 4.64% with the addition of 20% grape juice and to 7.72% with the addition of 40% grape juice. And Kawa-Rygielska et al. (2019) observed a decrease in wort pH from 5.81 to 3.55-3.77 with the addition of Cornelian cherry fruits.

Purple sweet potato wort had a lower content of soluble solids (11°Brix) and reducing sugars (4.99 g/100 mL) in relation to the other worts made with yellow sweet potatoes (PYSP and YSP) (15°Brix and 6.25-6.49 g/100 mL of reducing sugars). Humia et al. (2020) obtained a soluble solids content of 12°Brix in worts made with orange sweet potato flakes. According to Cadenas et al. (2021) sweet potatoes have excellent properties for use as an adjunct in the brewing industry, as they are mainly composed of starch and sugars and have a high content of β-amylases, which are more heat stable than barley β-amylases.

Purple sweet potato wort had a higher content of total phenolic compounds (187.02 mg/100 mL) compared to the other worts made with yellow sweet potatoes (PYSP and YSP) (90.85-93.37 mg/100 mL). Phenolic compounds are present in all sweet potato varieties, but the purple-fleshed one is especially known for its high anthocyanin content (Alam, 2021; Kurata et al., 2019; Wang et al., 2016). Im et al. (2021) reported values of total phenolic compounds from 180 to 737 mg/100 mL in purple sweet potato cultivars harvested in Korea.

Table 3 presents the physicochemical analyzes of the beers. The acidity of the sweet potato beers ranged from 0.33 to 0.36% and the pH from 4.31 to 4.35 and these values were comparable with the values of malted barley beers whose pH, in general, ranges from 3.80 to 4.70 (Ciont et al., 2022). Humia et al. (2020) reported a pH of 4.00-4.20 in beers made with orange sweet potato flakes.

Table 3. Physicochemical analyzes of the sweet potato beers.

Analyzes	Beers		
	PSP	PYSP	YSP
Acidity (%)	0.36 ± 0.00^{a}	0.34 ± 0.02^{a}	0.33 ± 0.02^{a}
pH	4.35 ± 0.00^{a}	4.31 ± 0.08^{a}	4.33 ± 0.17^{a}
Soluble solids (ºBrix)	6.50 ± 0.00^{a}	8.20 ± 0.00^{b}	8.00 ± 0.00^{b}
Reducing sugars (g/100 mL)	1.28 ± 0.15^{a}	1.40 ± 0.27^{a}	1.30 ± 0.02^{a}
Alcohol (% v/v)	4.50 ± 0.00^{a}	6.00 ± 0.00^{b}	6.00 ± 0.00^{b}
Phenolic compounds (mg/100 mL)	160.86 ± 6.82^{a}	110.84 ± 3.99^{b}	110.44 ± 7.24^{b}
ABTS (mM TE/mL)	3.22 ± 4.05^{a}	2.52 ± 4.35^{b}	2.38 ± 1.80^{b}
DPPH (mM TE/mL)	2.56± 2.28^{a}	1.57 ± 2.44^{b}	1.17 ± 2.12^{b}

PSP = Purple sweet potato beer, PYSP = purple and yellow sweet potato beer, YSP = yellow sweet potato beer. Data are represented as mean ± SD. Different superscript letters in the same row indicate significant differences ($p < 0.05$)

A reduction in the sugar content (1.28-1.40 g/100 mL) and soluble solids (5.50-8.20°Brix) was observed in sweet potato beers in relation to worts (sugars of 4.99-6.49 g/100 mL and 11.00-15.00°Brix), being an indicative of the consumption of fermentable sugars by brewing yeasts to produce ethanol. The beers made with orange sweet potato flakes presented a soluble solids content of 4.05-6.11°Brix (Humia et al., 2020). Cioch-Skoneczny et al. (2022) reported 4.45 to 5.39°Brix in beers with grape juice addition.

The alcohol content of purple sweet potato beer was lower (4.50%) than that of other beers made with yellow sweet potatoes (PYSP and YSP) (6.00%). This result was already expected, as the purple sweet potato wort had a lower soluble solids and sugar content. In general craft beers have an alcohol content range from 4.00 to 6.00% (Tirado-Kulieva et al., 2023). The beers made with orange sweet potato flakes had alcohol contents of 3.90-5.05% (Humia et al., 2020).

The total phenolic compound content of sweet potato beers ranged from 110.44 to 160.86 mg/100 mL. Brito Júnior et al. (2022) reported that values of 49.57 to 80.17 mg/100 mL of phenolic compounds were obtained for beers with addition of juçara fruit pulp, considering that ripe juçara fruit contains high contents of anthocyanins, which are pigments responsible for their dark purple color. Humia et al. (2020) also observed an increase in the content of phenolic compounds in beer made with 70% orange sweet potato flakes (23.05 mg/100 mL) compared to barley malt beer (21.09 mg/100 mL). Correia-Lima et al. (2024) used red beet peels as a brewing adjunct and observed that most of the phenolic compounds measured (epicatechin, catechin, epigallocatechin gallate, kaempferol 3-glucoside, caftaric acid, and trans-resveratrol) increased in supplemented beers with beetroot peels.

Caon et al. (2021) reported that craft beers have higher total phenolic compounds such as catechin, rutin, epicatechin, and caffeic acid than traditional beers. Some studies have shown that moderate alcohol consumption has beneficial properties against chronic diseases in healthy adult populations, including reduction of oxidative stress, inflammation, and cardiovascular diseases (Caon et al., 2021; Fernández-Solà, 2015; Quesada-Molina et al., 2019).

Purple sweet potato beer presented the highest antioxidant activity values (3.22- and 2.56-mM TE/mL of antioxidant activity by ABTS and DPPH) compared to the other beers (PYSP and YSP) (2.38-2.52 and 1.17-1.57 mM TE/mL of antioxidant activity by ABTS and DPPH). Humia et al. (2020) observed that the addition of orange sweet potato flakes in beers had a positive effect on the antioxidant activity, which can be related to its β-carotene and phenolic compounds content. Gasiński et al. (2023) also observed an increase in antioxidant activity using potatoes (*I. batatas*) with purple-colored flesh in beers. The authors obtained values of 2.01 and 2.38 of mM TE/dm^3 by ABTS in beers with the addition of 30 and 50% of potatoes, respectively, while the control beer presented 1.88 mM TE/dm^3. Brito Júnior et al. (2022) observed values of 1.19 to 3.97 of mM TE/100 mL of antioxidant activity by DPPH for beers with addition of juçara fruit pulp. Correia-Lima et al. (2024) reported that the use of red beet peels as a brewing adjunct in beer favored an increase in the antioxidant activity of beers. Rosales et al. (2021) reported that craft beers presented higher antioxidant activity when compared to commercial beers.

Sensory analysis of sweet potato beers

It is interesting to note that studies in the literature that added sweet potato or potato to beers utilized dried flakes (the sweet potato or potato flesh was cut into thin slices and dried to produce flakes) (Gasiński et al., 2023;

Figure 2. Aspect of the beers: a) Purple sweet potato beer; b) Purple and yellow sweet potato beer; c) Yellow sweet potato beer.

Table 4. Averages scores for the sensory attributes of sweet potato beers.

Sensory attributes	Beers		
	PSP	PYSP	YSP
Flavor	6.65 ± 0.12^{b}	8.00 ± 0.06^{a}	7.80 ± 0.02^{a}
Aroma	6.90 ± 0.25^{a}	7.30 ± 0.05^{a}	7.00 ±0.04^{a}
Color	7.00 ± 0.07^{a}	7.80 ± 0.10^{a}	6.50 ± 0.22^{b}
Foam persistency and carbonation	7.39 ± 0.08 ^{a}	7.80 ± 0.06^{a}	7.50 ± 0.12^{a}
Global impression	7.00 ± 0.15^{b}	8.20 ± 0.05^{a}	7.00 ± 0.10^{b}

PSP = Purple sweet potato beer, PYSP = purple and yellow sweet potato beer, YSP = yellow sweet potato beer. Values are represented as mean ± SD. Different superscript letters in the same row indicate significant differences ($p < 0.05$).

Humia et al., 2020), whereas the methodology of this study utilized moist, cooked, and mashed sweet potato flesh, which was suitable for beer production. The aspect of the beers is shown in Figure 2.

The sensory analysis of the beers produced with sweet potatoes is presented in Table 4. The beer with the best overall impression was the purple and yellow sweet potato beer (8.20), while the other beers (PSP and YSP) scored 7.00. Beers with the addition of purple sweet potatoes had higher scores for the color attribute (7.00-7.80) compared to yellow sweet potato beer (6.50), showing that evaluators were receptive to the purple color of these beers. The flavor of purple sweet potato beer had a lower score (6.65) than other beers (7.80-8.00). Perhaps the lower alcohol content in purple sweet potato beer had a negative influence on its flavor. The aroma, foam and carbonation attributes did not differ significantly between the beers.

Humia et al. (2020) observed similar results, where the beer with the addition of 30% orange sweet potato flakes obtained better acceptance than the beer with the addition of 70% orange sweet potato flakes and according to the authors the higher alcohol content of the 30% purple sweet potato beer increased complexity of volatile compounds, mainly aromatic esters. Gasiński et al. (2023) showed that the beer with the addition of 30% purple potato and the control beer were evaluated similarly in all sensory attributes tested, and the evaluators described the beer with 50% purple potato as having a strange flavor and unpleasant aftertaste. The results of the sensory analyzes in the studies show the importance of testing different beer formulations in the case of adding brewing adjuncts, to obtain the best beer formulation that pleases consumers.

Conclusion

The use of moist, cooked, and mashed sweet potato flesh as a brewing adjunct proved to be a viable alternative to produce beers. The sweet potato beers were well accepted in the sensory evaluation, with the purple and yellow-fleshed sweet potato beer being preferred by the evaluators. Furthermore, the production of beers with the addition of sweet potatoes resulted in beers with a high concentration of phenolic compounds and antioxidant activity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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