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Brief Report

The Effect of Food Processing on the Antioxidant Properties of *Ipomoea batatas*

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Abstract: It is known that heat treatment can lead to physical and chemical changes that can decrease or alter the properties of food. This work evaluated the influence on the antioxidant activity of boiling, pressure, and microwave cooking processes on three selected sweet potato varieties (purple, orange, and yellow). The samples were analyzed for total phenols and anthocyanin content and antioxidant capacity. The cooking water of the boiling and pressure processing were also analyzed. The results demonstrated that the purple sweet potato had better phenolic compounds, anthocyanins, and antioxidant activity profiles than the other varieties studied. On the other hand, the yellow sweet potato was the variety that showed the lowest antioxidant activity after applying the different culinary processes. Microwave processing, particularly when applied to purple sweet potato samples, seemed to be the most suitable cooking process to extract the bioactive compounds with antioxidant activity. Related to the cooking water, there were discrepancies between the behavior of different sweet potato varieties, since not all the samples followed similar profiles. In conclusion, it is necessary to study sweet potatoes processed through various cooking methods for antioxidant properties and other characteristics, such as texture, flavor, and nutritional value.

Keywords: *Ipomoea batatas*; sweet potato; food processing; cooking methods; phenols; anthocyanins; antioxidant activity

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1. Introduction

Tubers, which provide energy as they are rich in carbohydrates [1], play a significant role in human nutrition and are part of the largest group on the food pyramid. One of the most economically relevant tubers is the sweet potato, belonging to the *Convolvulaceae* family and scientifically known as *Ipomoea batatas* [2,3]. This plant is native to Central and South America and grows in tropical climates. Yet, it spread to various parts of the world between the 14th and 16th centuries, and from then on, it began to be of interest as a cultivated and commercial product [4]. The entire plant is edible, but in most countries, only the roots are consumed [5].

In general, a diet based on products of plant origin has proven to be advantageous in preventing several chronic diseases [6,7]. Sweet potatoes are rich in fiber, minerals, and phytochemicals that give them beneficial properties [6]. Moreover, they are abundant in phenolic compounds, flavonoids, carotenoids, and several essential minerals and vitamins [2,3,8]. Knowledge of the composition of foods is vital to establish a relationship with their bioactive properties. Thus, sweet potato is described as being associated with its antioxidant and anti-inflammatory properties [2,4]. In addition, it also has a protective activity for liver, gastrointestinal, neurological, and cardiac functions [2,4]. Another important property is the antitumor capacity associated with its phytochemical content, especially the phenolic compounds [6], which have antioxidant, anti-inflammatory, and

hypoglycemic properties, and are responsible for these properties in food [9,10]. Due to their high nutritional and energy values, sweet potatoes can be used in specific contexts as a functional food in the prevention of food shortages and situations of malnutrition [4,6]. Still, different sweet potato varieties have differences in composition. Purple sweet potato has a higher anthocyanin content, while phenolic compounds are abundant in yellow and orange sweet potatoes [8]. On the other hand, the culinary processes to which foods are subjected can lead to physical and chemical changes that can decrease or alter their properties [2,11–13].

This research studied the influence of different culinary processes (boiling, pressure, and microwave) on the antioxidant activity of three sweet potato varieties (purple, orange, and yellow). For this, the contents of phenolic compounds and anthocyanins were determined. The antioxidant capacity was also evaluated using the DPPH method in the different raw and processed samples, with and without peel, so that it would also be possible to compare the composition and bioactivity with these different characterization methods. Furthermore, the cooking water of the boiling and pressure processes were also analyzed.

2. Materials and Methods

2.1. Sweet Potato Samples

Three varieties of sweet potatoes (yellow, orange, and purple) were selected to study the influence of food processing on their antioxidant properties. The different varieties of sweet potatoes were purchased at a local supermarket and subsequently stored at 25 °C in a dry place away from light. Samples with and without peel were analyzed.

2.2. Cooking Processes

Three cooking techniques, boiling, pressure, and microwave, were studied under the conditions described in Table 1.

Table 1. Conditions of different cooking processes.

Cooking Process	Conditions	Equipment
Boiling	Temperature: 100 °C Time: 30 min	Magnetic stirrer heating plate with temperature control (Heidolph MR 3001 K, Heidolph Instruments, Schwabach, Nuremberg, Germany)
Pressure	Temperature: 121 °C Time: 15 min Pressure: 1.1 bar	Benchtop autoclave (Tuttnauer 2540 ML, Breda, Noord-Brabant, The Netherlands)
Microwave	Potency: 1200 W Time: 5 min	Kitchen microwave (Moulinex Micro-Time FM 1535 E, Groupe SEB Portugal, Lisbon, Portugal)

Sweet potato samples weighing 150 g were cut into small pieces to carry out the cooking processes. For the boiling and pressure-cooking techniques, it was ensured that the samples were completely submerged in 400 mL of distilled water.

The cooking water were separated from the processed sweet potato samples and then stored for later analysis. Both the raw and processed sweet potato samples were oven dried at 50 °C. Subsequently, the samples were subjected to extraction with ethanol/water (80/20, v/v), using a ratio of 5 g of sample to 100 mL of extraction solvent for 1 h in an ultrasound water bath at a temperature between 35 and 40 °C. Vacuum filtration was performed, followed by drying again in an oven at 50 °C until the extracts were completely dry. In the end, the different samples were weighed, and each dried extract was resuspended in methanol to obtain a solution with a concentration of 5 mg/mL.

2.3. Determination of the Total Phenolic Compounds

The total phenolics were quantified through a colorimetric method using the Folin–Ciocalteu reagent [14]. First, 50 µL of each methanolic extract solution at a concentration of 5 mg/mL or 50 µL of each cooking water, 450 µL of distilled water, and 2.5 mL of Folin–Ciocalteu reagent 0.2 N were placed in each test tube (the same volume of methanol was used in the test tube relative to the blank). After 5 min of incubation, 2 mL of a 75 g/L aqueous Na_2CO_3 solution was added. This was followed by an incubation period of 90 min at 30 °C and the determination of phenolic compounds by spectrophotometry at 765 nm. The calibration curve with standard solutions of gallic acid was previously performed. For this purpose, several methanolic solutions of gallic acid were used, thus obtaining a curve y = 0.001x, R^2 = 0.9845. All assays were performed in duplicate, and the total phenolic values were given in g of Gallic Acid Equivalents (GAE)/100 g of sweet potato.

2.4. Determination of the Anthocyanin Content

The anthocyanin content of the samples was determined using the differential pH method [15]. For this purpose, two buffer solutions with different pH values were used: 0.025 M potassium chloride at pH = 1 and 0.41 M sodium acetate at pH = 4.5.

First, 50 µL of each methanolic extract solution at a concentration of 5 mg/mL or 50 µL of each cooking water were placed in each test tube. The samples were then diluted with 4950 µL of each buffer solution. For the blank, distilled water was used. Subsequently, the absorbances were recorded at 520 nm and 700 nm. All assays were performed in duplicate.

The results were presented in mg of cyanidin-3-glucoside Equivalents (Eq)/100 g and mg of malvidin-3-glucoside Eq/100 g of sweet potato using the following equation:

$$\text{Anthocyanins} = \frac{A \times MW \times DF \times 10^3}{\varepsilon \times 1} \times \frac{100}{5} \quad (1)$$

$A = (A_{520\ nm} - A_{700\ nm})_{pH\ =\ 1.0} - (A_{520\ nm} - A_{700\ nm})_{pH\ =\ 4.5}$

MW (molecular weight) = 449.2 g/mol for cyanidin-3-glucoside and 463.3 g/mol for malvidin-3-glucoside

DF (dilution factor) = 100

10^3 = factor for conversion from g to mg

ε (molar extinction coefficient) = 26,900 L × mol^{-1} × cm^{-1} for cyanidin-3-glucoside and 28,000 L × mol^{-1} × cm^{-1} for malvidin-3-glucoside

1 = cuvette thickness in cm

100 = expresses the result in mg of anthocyanin Eq/100 g

5 = conversion from L to g, knowing that the concentration of methanolic extract solutions is 5 g/L.

2.5. Determination of the Antioxidant Activity

The antioxidant activity of the raw and processed sweet potatoes was determined using the DPPH (2,2-diphenyl-1-picrylhidrazyl) free radical scavenging assay [15].

First, 100 µL of each methanolic extract solution at a concentration of 5 mg/mL or 100 µL of each cooking water and 3.9 mL of the previously prepared 0.1 mM DPPH solution were added to the test tubes. The control tubes contained 100 µL of methanol and 3.9 mL of 0.1 mM DPPH solution, while the blank contained methanol. Then, all test tubes were shaken and left to react for 30 min at room temperature. The absorbances were recorded at 517 nm. All assays were performed in duplicate.

The results were presented in % inhibition using the following equation:

$$\%\ \text{inhibition} = \frac{A_{control} - A_{sample}}{A_{control}} \times 100 \quad (2)$$

$A_{control}$ = control absorbance

A_{sample} = sample absorbance

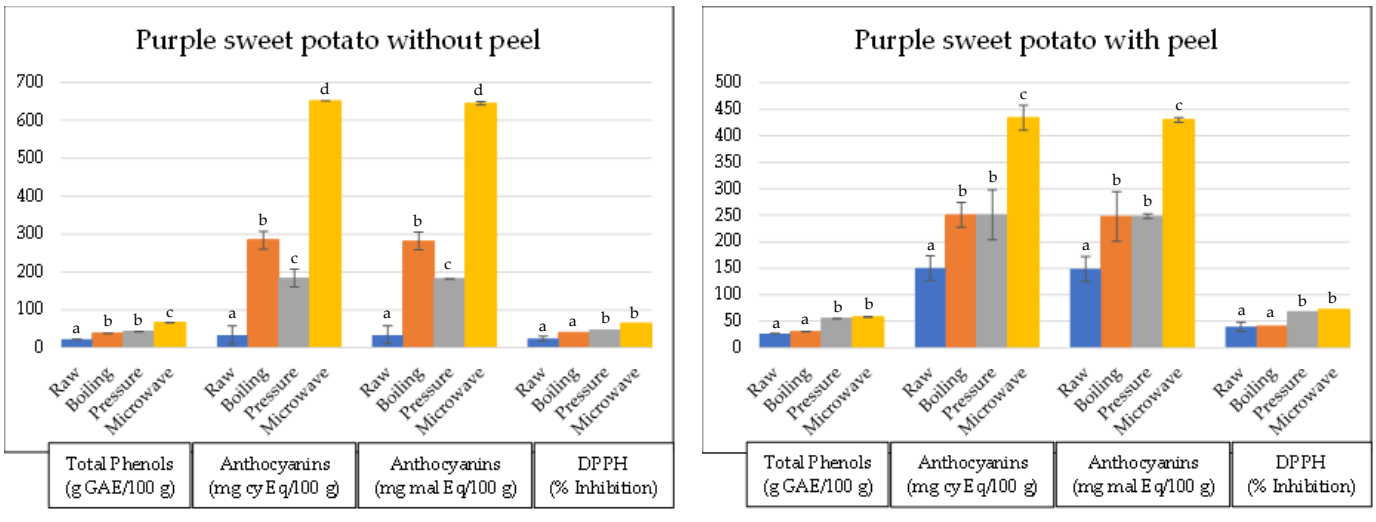
2.6. Statistical Analysis

The data were analyzed using the statistical program SPSS version 28.0.1. The mean values and standard deviation (SD) were calculated for all cases. One-way analysis of variance (ANOVA) was undertaken to test for significant differences among means ($p < 0.05$ was considered statistically significant).

3. Results and Discussion

In general, for each variety, sweet potatoes with peel had a higher total phenolics profile when compared to sweet potatoes without peel that were prepared through the same cooking method, which indicated that the peel retained this property even when different culinary processes were used (Figures 1–3). However, exceptions were observed in boiled and microwaved purple sweet potatoes (Figure 1) and boiled orange sweet potatoes (Figure 2). The raw purple sweet potato with peel, when compared to the purple sweet potato without peel, had an anthocyanin content 4.5 times higher when expressed in cyanidin-3-glucoside equivalents and 4.4 times higher when expressed as malvidin-3-glucoside (Figure 1). It was also observed that, for the same culinary process, purple sweet potatoes with peel presented a better antioxidant activity when compared to purple sweet potatoes without peel. The peel enriched the sweet potato regarding the phenolic compounds and/or anthocyanins, thus leading to higher antioxidant activity.

The purple sweet potato, with and without peel, presented higher phenolic compounds and anthocyanins when cooked in a microwave (Figure 1). This result was in line with the antioxidant activity of the microwave-processed purple sweet potato, which was higher than that of pressure and boiling treatments (Figure 1). For this variety, microwave processing proved more advantageous than the other cooking methods. Since the samples were not immersed in water as in the other processes, there were fewer structural changes in the microwaved samples [16]. This sweet potato variety also presented higher values of phenolic compounds than the other varieties subjected to the same processing conditions (Figure 1). When comparing the three varieties, the purple sweet potato had the highest antioxidant capacity. This association between total phenols and antioxidant activity, determined by the antiradical activity, was also observed in previous studies [17].



(**a**) (**b**)

Figure 1. The results obtained for purple sweet potatoes without peel (**a**) and purple sweet potatoes with peel (**b**); the mean values within the same set of results for each variable with different letters are significantly different ($p < 0.05$).

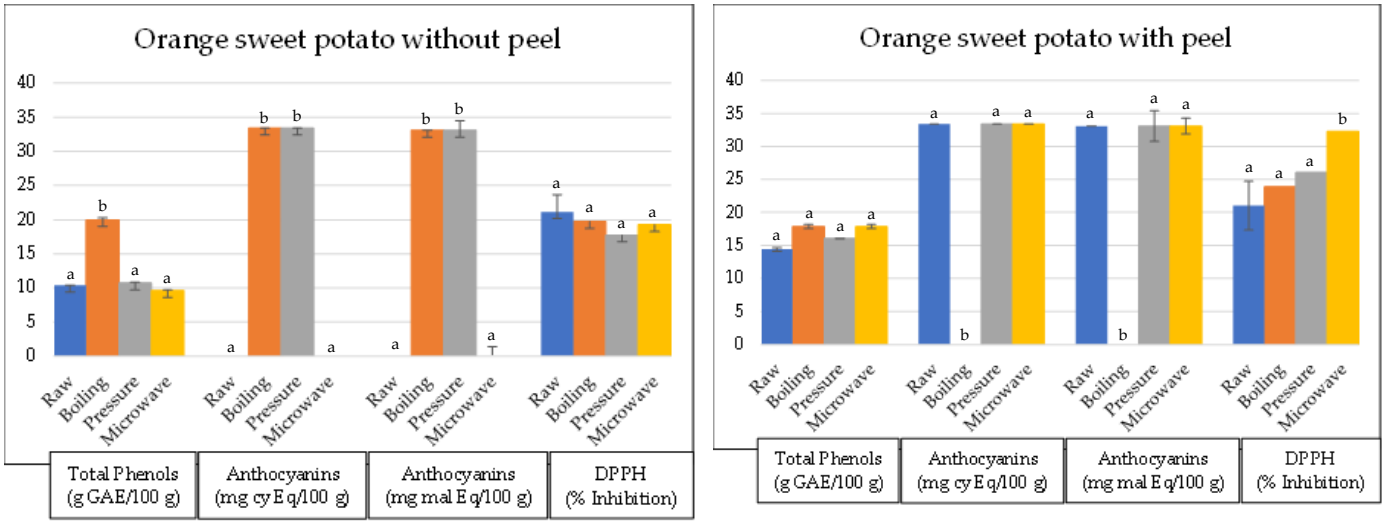


Figure 2. The results obtained for orange sweet potatoes without peel (**a**) and orange sweet potatoes with peel (**b**); the mean values within the same set of results for each variable with different letters are significantly different ($p < 0.05$).

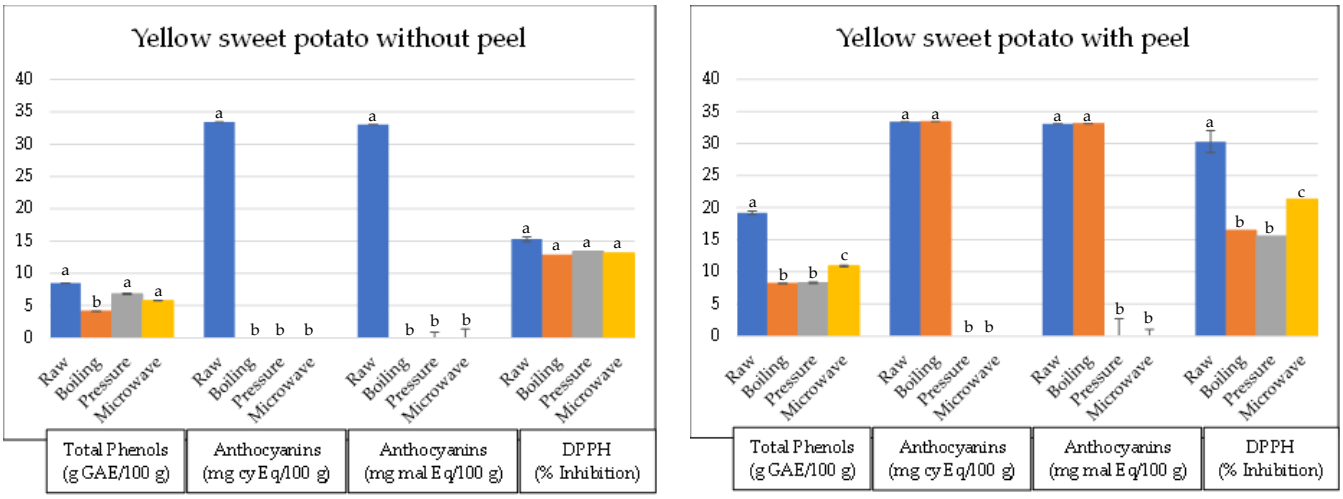


Figure 3. The results obtained for yellow sweet potatoes without peel (**a**) and yellow sweet potatoes with peel (**b**); the mean values within the same set of results for each variable with different letters are significantly different ($p < 0.05$).

Pressure-cooked purple sweet potato without peel had a lower anthocyanin value than the other culinary processes. However, the results of the boiled and pressure-cooked purple sweet potatoes with peel were similar (Figure 1).

After the different culinary processes, the sweet potato variety that demonstrated the lowest antioxidant activity was the yellow sweet potato (Figure 3). These findings agreed with previous studies that proved that purple sweet potatoes have a higher antioxidant activity compared to the orange and yellow varieties [18].

Previous studies have shown many differences in their results [11] that can be influenced by several factors such as the cooking time, the temperature to which food is subjected, and the presence or absence of water during cooking, as well as the pH and oxygen present in that water [11].

In most cases, for total phenols, the pressure treatment proved to be a more effective extractive process compared to the boiling treatment (Figures 4–6), except for the cooking water from the processed purple sweet potatoes without peel and the yellow sweet potatoes with peel (Figures 4 and 6). Under pressure conditions, there was an increased extraction of phenolic compounds, as these cooking water had higher total phenols' values. On the other hand, the cooking water of boiled purple sweet potatoes, with and without peel, had higher antioxidant activity than the samples treated under pressure conditions. A similar profile was observed in the cooking water of the orange sweet potatoes without peel and the yellow sweet potatoes with peel (Figures 5 and 6). These results diverged from the previous ones. In this case, the antioxidant activity was higher in the cooking water obtained through boiling.

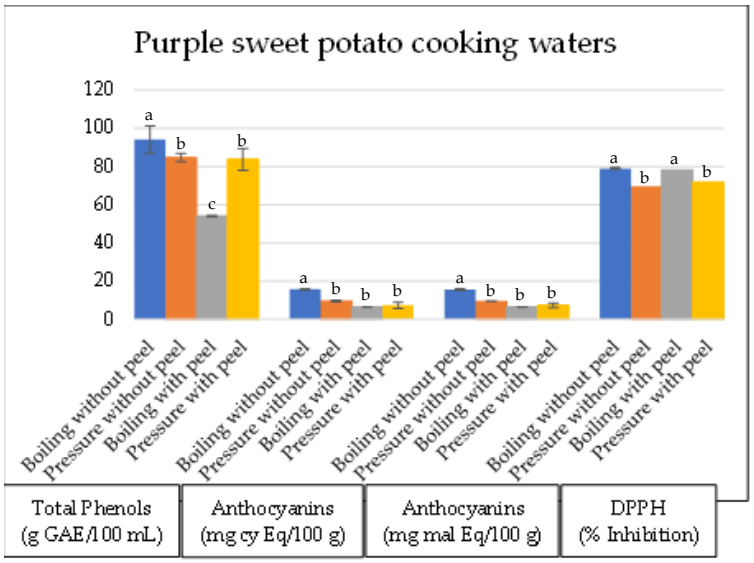


Figure 4. The results obtained for the purple sweet potato cooking water; the mean values within the same set of results for each variable with different letters are significantly different ($p < 0.05$).

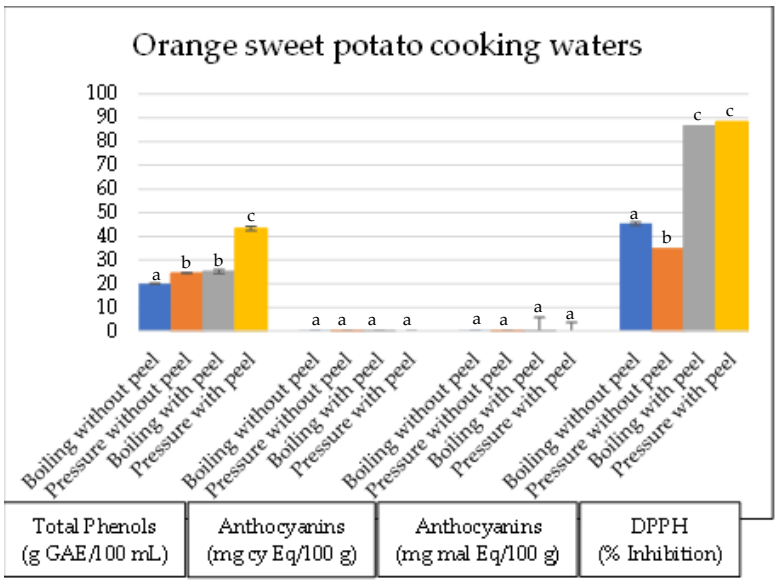


Figure 5. The results obtained for the orange sweet potato cooking water; the mean values within the same set of results for each variable with different letters are significantly different ($p < 0.05$).

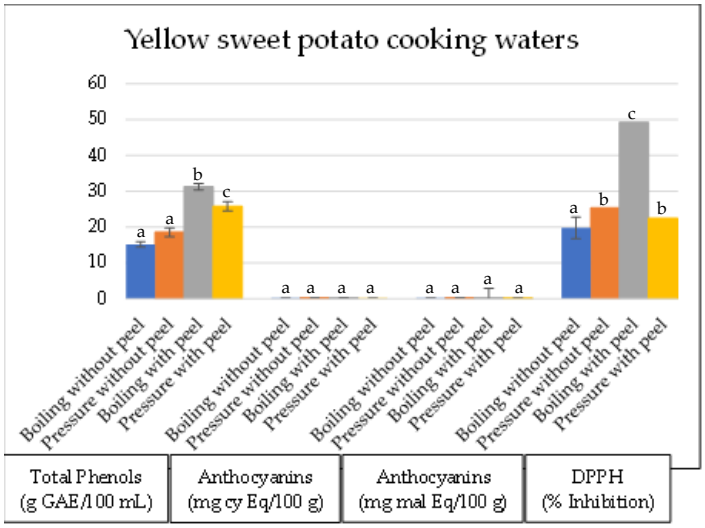


Figure 6. The results obtained for the yellow sweet potato cooking water; the mean values within the same set of results for each variable with different letters are significantly different ($p < 0.05$).

The cooking water from the processed purple sweet potato samples showed higher values of total phenols and anthocyanins when compared to all other cooking water (Figure 4). As expected, these results were consistent with the highest antioxidant activity observed for the cooking water (Figure 4).

Regarding the cooking water of the purple sweet potatoes, it was possible to prove that when the purple sweet potatoes were cooked without peel, the cooking water had a higher anthocyanin content than that of the purple sweet potatoes with peel. This suggests that the peel may reduce the passage of anthocyanins into the cooking water, but this was not observed in the other sweet potato varieties. On the other hand, the cooking water of the purple sweet potatoes with peel processed under the boiling and pressure conditions showed slight variations in anthocyanin values (Figure 4). This could reveal the resistance of the peel to processing conditions, but, once again, this was not observed for the other sweet potato varieties.

The cooking water of the boiled orange sweet potatoes without peel did not show any variation from the cooking water of the sample prepared through pressure (Figure 5). The cooking water from the pressure-processed orange sweet potato with peel did not contain anthocyanins (Figure 5).

The cooking water from the pressure-treated yellow sweet potato without peel had about twice the anthocyanin content of the cooking water from the boiled sample (Figure 6). However, this relationship was reversed in the cooking water from the yellow sweet potatoes with peel (Figure 6). In addition, the cooking water from the yellow sweet potatoes without peel processed under pressure conditions had a higher content of phenolic compounds when compared to the sample treated under boiling conditions. An inverse relationship was observed in the cooking water from the yellow sweet potatoes with peel. All this led to a similar profile in antioxidant activity for the cooking water (Figure 6).

It is important to note that potato processing generates waste in the form of peels, pulp, and rejects. Potato peel waste is produced as a byproduct in the processing of potatoes for food products such as potato chips and French fry fillets. However, potato peels are difficult to dispose of for the industry due to the high transportation cost of such waste. Moreover, this waste only provides marginal economic value when used as animal feed. Thus, there is a desire for new applications and utilization of potato peels which contain sufficient quantities of proteins, starch, cellulose, hemicellulose, and fermentable sugars [19,20].

4. Conclusions

Through this study, it was possible to conclude that not all sweet potato varieties showed identical behavior when subjected to different culinary processes. Microwave processing had the most significant benefits in preserving the properties of sweet potatoes, since it was the only process evaluated that did not involve submerging them in water during cooking.

Sweet potatoes with peel also proved advantageous in retaining the antioxidant properties over the same variety without the peel. Therefore, consuming sweet potatoes with peel is recommended independent from the chosen culinary process.

In general, food processing and heat treatments alter the structure and constituents of foods and, consequently, change their properties. As such, it is necessary to study sweet potatoes processed through various cooking methods for their antioxidant properties and other characteristics, such as texture, flavor, and nutritional value.

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