Characterization of the physicochemical, bromatological properties, and antioxidant activity of powdered sugarcane bagasse

Caracterización de las propiedades fisicoquímicas, bromatológicas y actividad antioxidante del bagazo de caña de azúcar en polvo

Caracterização das propriedades físico-químicas, bromatológicas e atividade antioxidante do bagaço de cana em pó

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Abstract

By-products are currently considered important foods for human consumption due to their large contribution of bioactive compounds. The objective of the study was to characterize the physicochemical, bromatological, and antioxidant properties of powdered sugarcane bagasse. To obtain sugarcane bagasse powder (PBCA), samples were collected in three artisanal sugar mills in the Junín canton, province of Manabí. The samples were labeled under the codes; M1, M2, and M3. An analysis of variance and Tukey's test at 5 % significance were applied. Statistical significance was determined between the samples evaluated, the results demonstrated a variation in the physicochemical properties: pH (5.96 ± 0.01 – 7.14 ± 0.05); acidity (0.09 ± 0.00 – 0.37 ± 0.00 %); moisture (5.05 ± 0.32 – 9.80 ± 0.68 %) and ash (1.94 ± 0.00 – 4.47 ± 0.02 %), bromatological: crude fiber (13.85 ± 0.11 – 24.39%); protein (0.16 ± 0.00 – 0.86 ± 0.01 %); dry matter (88.52 ± 3.51 – 94.94 ± 0.32%) and fat (0.09 ± 0.00 – 0.13 ± 0.01%), functional and antioxidant compounds: hemicellulose (25.32 ± 0.79 %); cellulose (17.90 ± 0.05 – 26.83 ± 0.20%); lignin (0.31 ± 0.00 – 0.51 ± 0.00 %); water retention capacity (3.27 ± 0.01 – 4.93 ± 0.19 g $H_2O.g^{-1}$); antioxidant activity (3.70 ± 0.03 – 9.92 ± 9.12 µmol trolox equivalent.g^{-1}) and total phenols (2.19 ± 0.00 – 13.35 ± 0.03 mg gallic acid equivalent.g^{-1}). All samples were microbiologically acceptable. PBCA presented nutritional characteristics of importance for the formulation of products for human consumption.

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Resumen

Los subproductos actualmente son considerados alimentos de importancia para el consumo humano por su gran aporte de compuestos bioactivos. El estudio tuvo como objetivo caracterizar las propiedades fisicoquímicas, bromatológicas y antioxidantes del bagazo de caña de azúcar en polvo. Para la obtención del polvo de bagazo de caña de azúcar (PBCA) se recolectaron muestras en tres trapiches artesanales del cantón Junín provincia de Manabí. Las muestras se etiquetaron bajo los códigos; M1, M2 y M3. Se aplicó un análisis de varianza y prueba de Tukey al 5 % de significancia. Se determinó significancia estadística entre las muestras evaluadas, los resultados demostraron una variación de las propiedades fisicoquímicas: pH (5,96 ± 0,01 – 7,14 ± 0,05); acidez (0,09 ± 0,00 – 0,37 ± 0,00 %); humedad (5,05 ± 0,32 – 9,80 ± 0,68 %) y cenizas (1,94 ± 0,00 – 4,47 ± 0,02 %), bromatológicas: fibra cruda (13,85 ± 0,11 – 24,39 %); proteína (0,16 ± 0,00 – 0,86 ± 0,01 %); materia seca (88,52 ± 3,51 – 94,94 ± 0,32 %) y grasa (0,09 ± 0,00 – 0,13 ± 0,01 %), compuestos funcionales y antioxidantes: hemicelulosa (25,32 ± 0,79 %); celulosa (17,90 ± 0,05 – 26,83 ± 0,20 %); lignina (0,31 ± 0,00 – 0,51 ± 0,00 %); capacidad de retención de agua (3,27 ± 0,01 – 4,93 ± 0,19 g $H_2O.g^{-1}$); actividad antioxidante (3,70 ± 0,03 – 9,92 ± 9,12 µmol trolox equivalente.g^{-1}) y fenoles totales (2,19 ± 0,00 – 13,35 ± 0,03 mg ácido gálico equivalente.g^{-1}). Todas las muestras fueron microbiológicamente aceptables. El PBCA presentó características nutricionales de importancia para la formulación de productos de consumo humano.

Palabras clave: antioxidantes, fenoles totales, fibra, polvo de bagazo de caña.

Resumo

Os subprodutos são atualmente considerados alimentos importantes para consumo humano devido à sua grande contribuição de compostos bioativos. O objetivo do estudo foi caracterizar as propriedades físico-químicas, bromatológicas e antioxidantes do bagaço de cana em pó. Para a obtenção do pó de bagaço de cana-de-açúcar (PBCA), foram coletadas amostras em três usinas artesanais de açúcar do cantão Junín, província de Manabí. As amostras foram rotuladas sob os códigos; M1, M2 e M3. Foram aplicados análise de variância e teste de Tukey a 5 % de significância. Foi determinada significância estatística entre as amostras avaliadas, os resultados demonstraram variação nas propriedades físico-químicas: pH (5,96 ± 0,01 – 7,14 ± 0,05); acidez (0,09 ± 0,00 – 0,37 ± 0,00%); umidade (5,05 ± 0,32 – 9,80 ± 0,68 %) e cinzas (1,94 ± 0,00 – 4,47 ± 0,02 %), bromatológicas: fibra bruta (13,85 ± 0,11 – 24,39 %); proteína (0,16 ± 0,00 – 0,86 ± 0,01 %); matéria seca (88,52 ± 3,51 – 94,94 ± 0,32 %) e gordura (0,09 ± 0,00 – 0,13 ± 0,01 %), compostos funcionais e antioxidantes: hemicelulose (25, 32 ± 0,79 %); celulose (17,90 ± 0,05 – 26,83 ± 0,20 %); lignina (0,31 ± 0,00 – 0,51 ± 0,00 %); capacidade de retenção de água (3,27 ± 0,01 – 4,93 ± 0,19 g $H_2O.g^{-1}$); atividade antioxidante (3,70 ± 0,03 – 9,92 ± 9,12 µmol equivalente trolox.g^{-1}) e fenóis totais (2,19 ± 0,00 – 13,35 ± 0,03 mg equivalente ácido gálico.g^{-1}). Todas as amostras eram microbiologicamente aceitáveis. PBCA apresentou características nutricionais importantes para formulação de produtos para consumo humano.

Palavras-chave: antioxidantes, fenóis totais, fibra, bagaço de cana em pó.

Introduction

Sugarcane (*Saccharum officinarum* L.) is one of the most important crops in the world, native to Southeast Asia, it is a perennial grass of the family Poaceae (Largo *et al.,* 2014; Suárez *et al.,* 2018). In 2020, it had a global production of approximately 166,18 million metric tons (Jiménez *et al.,* 2023). It is mostly grown in tropical and subtropical countries in Africa, Asia, Latin America, and the Caribbean (Velázquez *et al.,* 2021).

In Ecuador, it is estimated that there are 110,000 ha of sugarcane crops, 74,100 are destined for sugar production and the rest for panela production (Verdezoto *et al.,* 2021), currently, 98 % is consumed in the domestic market (Quishpe *et al.,* 2020). The provinces with the highest cultivation are Guayas, Loja, and Cañar, responsible for 97 % of the volume produced. However, the province of Manabí has about 1,369 ha planted with sugarcane, of which about 700 hectares are in the canton of Junín, with an annual production of 45,000 t, which are mostly destined for the production of *aguardientes* (Cartay *et al.,* 2019).

In the sugarcane industry, after its processing, a variety of agricultural residues are obtained, among which are; bud and green leaves (8 %), dried pods and leaves (20 %), and industrial by-products derived from the manufacture, not only panela but also of sugar such as bagasse, *bagacillo*, cachaça, *melot*e, molasses and vinasse (Lagos and Castro, 2019).

Regarding bagasse, about 234 million tons of this waste are produced worldwide (López *et al.,* 2016). According to Aguilar (2019), when 100 t of sugarcane are processed, about 30 t of sugarcane bagasse (fiber and pith) are generated. This agroresidue is obtained after squeezing the stems; and has different uses, such as; in the production of paper, as fuel, in the production of second-generation ethanol (De la Torre *et al.,* 2021), fertilizers (Arias *et al.,* 2021), cellulosic products (Torgbo *et al.,* 2021), solid biofuels (Manzini *et al.,* 2022) and its use as a source of fiber in biscuits (Vijerathna *et al.,* 2019).

Although there are alternatives for industrial use, this waste continues to be a problem in Ecuador for small sugarcane producers in the Junín canton in the province of Manabí, who process this raw material in artisanal mills, through practices transmitted from generation to generation to obtain different derivatives of sugarcane (*aguardientes*, sandwiches, panela) (Resano *et al.,* 2022), the difficulty arises because producers only use a part of the by-product as livestock feed, and the rest is discarded and burned, which generates environmental pollution and health problems in the inhabitants of nearby communities.

Indeed, the surplus of sugarcane bagasse causes health, economic, and environmental problems in society, which is why it is necessary to give added value through agro-industrial transformation into powder and subsequently, carry out studies on its chemical composition to obtain results of scientific quality that allow generating greater interest in this by-product to be included in food processes for human consumption. Therefore, this study aimed to characterize the physicochemical and bromatological properties and antioxidant activity of powdered sugarcane bagasse (*Saccharum officinarum* L.).

Materials and methods

Location of the trial

The process of transforming sugarcane bagasse into powder was carried out in the Agroindustrial Processes Laboratory, fruit and

vegetable area of the Faculty of Agrosciences, Technical University of Manabí.

The characterization of the physicochemical, bromatological, antioxidant properties and the microbiological evaluation of sugarcane bagasse powder was developed in the Biochemistry, Bromatology, and Microbiology Laboratories of the Faculty of Agrosciences of the Technical University of Manabí.

Plant material

The plant material of the sugarcane bagasse was obtained from three micro-enterprises in the Junín canton of the province of Manabí, the following; Aguardiente de Caña Barreiro (M1); Aguardiente tres Hermanos (M2) and Aguardiente Santa Ana (M3). Samples were collected every 24 hours for three days.

Obtaining sugarcane bagasse powder

Samples of sugarcane bagasse were received, which were collected dry in the open air after the harvest process in the artisanal mills of the Junín canton, later, they were taken to the laboratory of agro-industrial processes to carry out the process of obtaining sugarcane bagasse powder.

The different samples of sugarcane bagasse were dehydrated for six (6) hours at a temperature of 60 °C, for which a dehydrator (BYR brand) with a capacity of 12 stainless steel trays was used.

The dehydrated samples were added to an electric mill with stainless steel blades and the dehydrated bagasse was ground for three (3) minutes; then the PBCA was sieved on a No. 120 sieve to obtain a particle size of 125 mm; subsequently, the sugarcane bagasse powder was packaged in vacuum-sealed double-sealed polyethylene plastic bags and stored at room temperature (28 °C).

Physicochemical, bromatological, and antioxidant properties

A physicochemical, bromatological and antioxidant characterization was carried out in each sample of sugarcane bagasse powder through the following analyses; moisture and dry matter by the method (NTE INEN-ISO 712); acidity by the method (NTE INEN 521); pH (NTE INEN-ISO 1842); ashes (NTE INEN-ISO 2171); crude fiber (AOAC 962.09); protein (NTE INEN-ISO 20483); fat (NTE INEN-ISO 20483); hemicellulose, cellulose and lignin by test method (AKOM, AOAC 2002:04/AOAC 973.18) and water-holding capacity (gravimetric method).

Antioxidant activity was determined using the spectrophotometric/ABTS method, reported by Re *et al.* (1999), for this purpose, a working solution with an absorbance between 0.8 and 1 at 734 nm was prepared by dissolving the ABTS+ radical stored with methanol for 16 hours until the established values were achieved, then 1 mL of sample and control (extract dilution medium) and 1 mL of the prepared radical were added in a test tube, and it was stirred with the help of a vortex and left to react for 1 hour. After the established time, the absorbance was measured at 734 nm using a spectrophotometer (Evolution ™ 201/220 UV-Vis Thermo Scientific ™, Waltham, Ma, EE. UU). Antioxidant activity was expressed in µmol trolox equivalent g^{-1} of the PBCA sample.

The determination of total phenols was performed following the spectrophotometric/Folin Ciocalteu method, proposed by Sultana *et al.* (2009) with some modifications, 200 µL of the standardized sample was taken, then 1.5 mL of distilled water was added and 100 µL of Folin-Ciocalteu reagent (phosphomolybdic acid + phosphotungstic acid) was added, subsequently, it was left to rest for five (5) minutes, 200 uL of 20 % sodium carbonate m/v was added to the resulting solution. The solution was allowed to stand for one (1) hour at room temperature in the dark and then the absorbance reading on a UV-vis spectrophotometer (Evolution™ 201/220 UV-Vis Thermo Scientific™, Waltham, Ma, USA) at 760 nmol. Phenol content was expressed in mg gallic acid equivalent g^{-1} of the PBCA sample.

Microbiological evaluation

The microbiological quality of sugarcane bagasse powder samples was evaluated by the following analyses: Molds and yeasts using the NTE INEN 1529-10 AOAC 997.02 method and *E. coli* using the NTE INEN 1529-8 AOAC 991.14 test method.

Experimental design and statistical analysis

A completely randomized design with factorial arrangement was applied, and the factor under study corresponded to samples of sugarcane bagasse powder (PBCA) from different artisanal microenterprises in the Junín canton. The microenterprises were named with the codes M1, M2, and M3, three replications were carried out per sample, obtaining a total of nine (9) experimental units (table 1).

Table 1. Sugarcane bagasse powder samples (PBCA).

Samples	Code	Repetitions
1	M1	3
2	M2	3
3	M3	3

Minitab 18 statistical software was used. An analysis of variance and Tukey's multiple comparison test were applied at 95 % confidence and 5 % significance. Results were expressed as mean ± standard deviation.

Results and discussion

Physicochemical, bromatological, and antioxidant properties of sugarcane bagasse powder

Table 2 presents the results of the characterization of the physicochemical properties of sugarcane bagasse powder samples. It was observed that the variables under study showed statistical significance with each other.

A lower pH value (5.96 ± 0.01) was determined at hour 0 for M2 and a higher pH (6.87 ± 0.05) for M1, however, the pH was higher at 24 and 48 hours of evaluation for M2 (7.14 ± 0.05 - 7.12 ± 0.00). The pH values in this research ranged from acidic to neutral, similar to the results obtained by Zara *et al.* (2017) with a pH value of 6.65 ± 0.031 for sugarcane bagasse.

Regarding the acidity of sugarcane bagasse powder, a higher value was observed for M3 (0.26 ± 0.00 %) at time 0, for M1 0.22 ± 0.00 % at 24 hours, and for M2 0.37 ± 0.00 % at 48 hours, this parameter was variable between samples and times. The acidity levels are close to the limit required by the NTE INEN 616 (2015) standard for flours, which indicates a maximum between 0.2 – 0.3 %.

The percentage of moisture at time 0 was higher in M2 presenting a value of 9.44 ± 1.09 %, on the contrary, at 24 and 48 hours of evaluation M1 presented higher moisture (9.80 ± 0.68 % – 9.35 ± 0.55 %), in the three times, M3 was the sample with the lowest moisture content, these results are within the limit required by the Ecuadorian regulation NTE INEN 616 (2015) which indicates that flours must present moisture between 14.5 % - 15 %, the lower the moisture percentage, the better the conservation of the product.

Table 2. Physicochemical characterization of sugarcane bagasse powder samples.

Physicochemical Parameters	PBCA		Evaluation time in hours (h)		
			0 h	24 h	48 h
pH	M1		6.87 ± 0.05^{A}	6.93 ± 0.05^{B}	6.86 ± 0.02^{C}
	M2		5.96 ± 0.01^{C}	7.14 ± 0.05^{A}	7.12 ± 0.00^{A}
	M3		6.11 ± 0.01^{B}	7.02 ± 0.01^{B}	6.99 ± 0.01^{B}
		Sig.	0.000	0.004	0.000
Acidity (%)	M1		0.16 ± 0.00^{C}	0.22 ± 0.00^{A}	0.17 ± 0.00^{B}
	M2		0.25 ± 0.00^{B}	0.17 ± 0.00^{B}	0.37 ± 0.00^{A}
	M3		0.26 ± 0.00^{A}	0.09 ± 0.00^{C}	0.12 ± 0.00^{C}
		Sig.	0.000	0.000	0.000
Moisture (%)	M1		8.38 ± 0.59^{AB}	9.80 ± 0.68^{A}	9.35 ± 0.55^{A}
	M2		9.44 ± 1.09^{A}	9.61 ± 0.55^{A}	7.28 ± 1.20^{B}
	M3		6.99 ± 0.17^{B}	5.65 ± 0.04^{B}	5.05 ± 0.32^{C}
		Sig.	0.018	0.000	0.002
Ash (%)	M1		2.29 ± 0.07^{C}	2.08 ± 0.00^{B}	1.94 ± 0.00^{C}
	M2		2.44 ± 0.07^{B}	4.40 ± 0.07^{A}	4.47 ± 0.02^{A}
	M3		4.17 ± 0.00^{A}	4.31 ± 0.00^{A}	4.26 ± 0.06^{B}
		Sig.	0.000	0.000	0.000

Averages that do not share a letter in superscripts are significantly different.

Ash concentrations were lower at time 0, 24, and 48 hours for M1, whose results ranged from 2.29 ± 0.07 – 2.08 ± 0.00 – 1.94 ± 0.00 %, while the highest values were obtained for M3 (0 hours) 4.17 ± 0.00 % and M2 (24 and 48 hours) 4.40 ± 0.07 – 4.47 ± 0.02 %. The values obtained in this research are below those published by Guilherme *et al.* (2015) who determined an ash content in sugarcane bagasse of 8.80 ± 0.02 % (dry basis), which allowed corroborating that this residue can be reduced when processed into powder. Ash concentrations can vary according to the climatic and harvest conditions of each producer in sugarcane crops.

Bromatological analysis of sugarcane bagasse powder

Table 3 shows the results obtained in the determination of the bromatological properties of sugarcane bagasse powder samples.

The analysis of variance determined that the variables; crude fiber and protein showed statistically significant differences ($p<0.05$). In dry matter, with the exception of 24 h time, the samples were statistically significant ($p<0.05$). Regarding the fat variable, no statistical significance ($p>0.05$) was observed at time 0 and 48 h, while at 24 h there was statistical significance.

According to the results presented in table 3, during the first and third crude fiber evaluations, the levels of this parameter were lower (15.13 ± 1.33 % - 13.85 ± 0.11 %) in M1 and higher (19.36 ± 0.06 % - 24.39 ± 0.19 %) in M2 at the 24 and 48 h of evaluation, however, all PBCA samples presented fiber levels of importance for feeding. Studies such as that of Jácome *et al.* (2023) have shown that sugarcane can have a crude fiber content of up to 27.9 %.

Regarding the protein variable, the values varied between samples, with M1 being the highest value (0.20 ± 0.01 %) at time 0, however, the higher values were maintained in the second and third evaluations in M2 (0.86 ± 0.01 % - 0.50 ± 0.01 %). Selim *et al.* (2022) determined a higher protein content in sugarcane bagasse (3.81 ± 0.07 %), i.e. protein levels can decrease when sugarcane bagasse is converted into powder. Likewise, Hurtado *et al.* (2021) reported higher crude protein contents (3.78 ± 0.09 %) for fermented sugarcane bagasse over 30 days.

Concerning dry matter content, M2 was the PBCA sample with the lowest content (90.55 ± 1.09 %) at 0 h. However, the sample with the highest value was M3 during all evaluation times (93.00 ± 0.17 %, 94.34 ± 0.04 %, 94.94 ± 0.32 %), averages that are related to those published by Gil *et al.* (2019) who determined the content of 92.50 ± 0.46 % DM for sugarcane bagasse fiber.

The fat results were not so variable (0.09 ± 0.00 % - 0.13 ± 0.00 %), the sample with the highest value was M3 between 24 and 48h. Studies such as that of Vijerathna *et al.* (2019) determined a higher fat content (1.04 ± 0.05 %) in sugarcane bagasse powder samples. It should be noted that the amount of fat present in the sugarcane bagasse corresponds to the layer of wax found on the outside of the sugarcane husk.

Functional and antioxidant properties of sugarcane bagasse powder

Table 4 presents the results of the analysis of variance performed on the functional and antioxidant profile variables of sugarcane bagasse powder samples.

No significant differences ($p>0.05$) were observed during time 0 in hemicellulose, 48h in lignin, and 24h in antioxidant activity. There were significant differences in the rest of the variables ($p<0.05$).

Hemicellulose values ranged from 25.32 ± 0.79 % to 38.65 ± 1.70 %, with M3 having the highest content at 24 and 48h of evaluation. Regarding the cellulose content, the values were variants, it was shown that M1 was the one with the lowest value at 0 and 24h (20.33

Table 3. Bromatological characterization of sugarcane bagasse powder samples.

Bromatological Parameters	PBCA		Evaluation time in hours (h)		
			0 h	24 h	48 h
Crude fiber (%)	M1		15.13 ± 1.33^{B}	18.39 ± 0.08^{B}	13.85 ± 0.11^{C}
	M2		18.19 ± 0.02^{A}	19.36 ± 0.06^{A}	24.39 ± 0.19^{A}
	M3		19.97 ± 0.66^{A}	16.57 ± 0.29^{C}	19.26 ± 0.06^{B}
		Sig.	0.001	0.000	0.000
Protein (%)	M1		0.20 ± 0.01^{A}	0.16 ± 0.00^{B}	0.45 ± 0.00^{B}
	M2		0.17 ± 0.00^{B}	0.86 ± 0.01^{A}	0.50 ± 0.01^{A}
	M3		0.17 ± 0.00^{B}	0.85 ± 0.02^{A}	0.42 ± 0.00^{C}
		Sig.	0.010	0.000	0.000
Dry matter (%)	M1		91.61 ±0.59^{AB}	88.52 ± 3.51^{A}	90.64 ± 0.55^{C}
	M2		90.55 ± 1.09^{B}	93.05 ± 5.06^{A}	92.71 ± 1.20^{B}
	M3		93.00 ± 0.17^{A}	94.34 ± 0.04^{A}	94.94 ± 0.32^{A}
		Sig.	0.018	0.191	0.002
Fat (%)	M1		0.13 ± 0.01^{A}	0.09 ± 0.00^{B}	0.11 ± 0.00^{A}
	M2		0.11 ± 0.00^{A}	0.13 ± 0.00^{A}	0.11 ± 0.00^{A}
	M3		0.12 ± 0.02^{A}	0.13 ± 0.00^{A}	0.13 ± 0.00^{A}
		Sig.	0.330	0.000	0.050

Averages that do not share a letter in superscripts are significantly different.

± 0.13 % - 18.29 ± 0.74 %), however, the sample with the highest value in cellulose was M2 (26.83 ± 0.20 % - 19.97 ± 0.54 %) at 24 and 48h. According to Ameram *et al.* (2019), these compounds are found in the cell wall of sugarcane bagasse biomass.

The results of this study are close to those reported by Widjaja *et al.* (2019) who obtained 32.8 % cellulose and 26.3 % hemicellulose in untreated sugarcane bagasse. According to De Moraes *et al.* (2015), the hemicellulose fraction is a heteropolymer of pentose and hexoses, in which xylans predominate, and the cellulose fraction is a homopolymer of glucose. Lignocellulosic material contents are of interest for the production of value-added compounds such as ethanol, food additives, organic acids, enzymes, antioxidants, and others.

The lignin content was variable (0.31 ± 0.00 % - 0.51 ± 0.00 %) for the different PBCA samples, with M1 having the lowest lignin content at time 0 and the highest M3 value (0.38 ± 0.03 %), however, M3 was the one with the lowest value at 24h of evaluation with a mean of 0.36 ± 0.05 %. Higher lignin values were obtained by Qiu *et al*. (2012) in untreated sugarcane bagasse, 24.81 ± 0.14 % in total lignin, 20.83 ± 0.22 % in acid-insoluble lignin, and 3.98 ± 0.08 % in acid-soluble lignin. On the other hand, studies such as that of De Moraes *et al.* (2015) indicated a variation in lignin between 21.56 ± 1.67 % total lignin, 7.38 ± 2.13% soluble lignin, and 1.17 ± 0.06 insoluble lignin. Lignin content is variable within sugarcane plant populations of the same species.

The highest value of water-holding capacity (WHC) was presented by M1 at 0 h (4.80 ± 0.30 g $H_2O.g^{-1}$). At 24 h, M2 was the sample with the highest value: 4.93 ± 0.19 g $H_2O.g^{-1}$. However, in all samples of sugarcane bagasse powder, a range of WHC between 4.50 ± 0.01 and 4.44 ± 0.01 g $H_2O.g^{-1}$ was determined at 24 and 48h.

The PBCA sample with the highest antioxidant activity value was M2 during the first two evaluation times (9.92 ± 9.12 7.12 ± 3.27 µmol trolox equivalent.g^{-1}), however, at 48h M1 presented a higher value (9.85 ± 0.12 µmol trolox equivalent.g^{-1}). Mohamed *et al.* (2021) obtained higher ranges in antioxidant activity for ground sugarcane bagasse, since they used different solvents (ethanol, water-methanol) to obtain the extracts, presenting values between 26.3 ± 0.21 – 54.0 ± 0.14 % by the DPPH method.

Regarding total phenols, M2 presented a higher content during the 0 and 24 h evaluation time (13.35 ± 0.03 - 11.16 ± 0.01 mg gallic acid equivalent.g^{-1}), however, at 48h, M1 presented a higher value (7.64 ± 0.04 mg gallic acid equivalent.g^{-1}) compared to the other samples. Studies conducted by Prasong *et al.* (2021) determined a variable total phenolic content in three different samples of ground sugarcane bagasse; AU17 (12.13 ± 0.33 mg GAE); SP50 (6.64 ± 0.00 mg GAE) and SP72 (8.11 ± 0.28 mg GAE). According to Jiménez *et al.* (2014), sugarcane bagasse is a by-product rich in bioactive compounds (total phenols and antioxidants).

Microbiological quality of sugarcane bagasse powder

Table 5 shows the microbial load present in the different samples of sugarcane bagasse powder.

It was determined that the microorganism molds and yeasts, maintained a variation between samples from 1.2 x 10^3 – 9.2 x 10^2 CFU.g^{-1}, regarding the count of *E. coli,* it was demonstrated that the absence of this pathogen was demonstrated, these results are within the limit required by the reference standard NTE INEN 616 (2015).

Table 4. Characterization of the functional and antioxidant parameters of sugarcane bagasse powder samples.

Functional parameters and antioxidants	PBCA		Evaluation time in hours		
			0 h	24 h	48 h
Hemicellulose (%)	M1		26.94 ± 1.74^{A}	25.32 ± 0.79^{B}	27.20 ± 2.08^{B}
	M2		25.86 ± 0.24^{A}	29.40 ± 0.85^{A}	37.99 ± 1.73^{A}
	M3		26.35 ± 0.40^{A}	30.80 ± 1.86^{A}	38.65 ± 1.70^{A}
		Sig.	0.493	0.005	0.000
Cellulose (%)	M1		20.33 ± 0.13^{B}	18.29 ± 0.74^{B}	23.99 ± 0.04^{A}
	M2		25.94 ± 1.16^{A}	26.83 ± 0.20^{A}	19.97 ± 0.54^{B}
	M3		26.05 ± 0.81^{A}	26.08 ± 0.29^{A}	17.90 ± 0.05^{C}
		Sig.	0.000	0.000	0.000
Lignin (%)	M1		0.31 ± 0.00^{B}	0.51 ± 0.00^{A}	0.35 ± 0.03^{A}
	M2		0.33 ± 0.00^{B}	0.42 ± 0.01^{B}	0.38 ± 0.00^{A}
	M3		0.38 ± 0.03^{A}	0.36 ± 0.05^{B}	0.36 ± 0.00^{A}
		Sig.	0.010	0.003	0.087
WHC (g $H_2O.g^{-1}$)	M1		4.80 ± 0.30^{A}	4,77 ±0.01^{AB}	4.10 ± 0.01^{B}
	M2		3.27 ± 0.01^{C}	4.93 ± 0.19^{A}	4.14 ± 0.02^{B}
	M3		3.94 ± 0.03^{B}	4.50 ± 0.01^{B}	4.44 ± 0.01^{A}
		Sig.	0.000	0.009	0.000
A.A (µmol trolox equivalent.g^{-1})	M1		6.45 ± 0.03^{B}	7.11 ± 2.21^{A}	9.85 ± 0.12^{A}
	M2		9.92 ± 9.12^{A}	7.12 ± 3.27^{A}	3.70 ± 0.03^{B}
	M3		5.19 ± 0.04^{C}	3.79 ± 0.17^{A}	3.78 ± 0.08^{B}
		Sig.	0.000	0.157	0.000
T.P. (mg gallic acid equivalent.g^{-1})	M1		9.43 ± 0.05^{B}	5.47 ± 0.02B	7.64 ± 0.04^{A}
	M2		13.35 ± 0.03^{A}	11.16 ± 0.01A	1.70 ± 0.01^{C}
	M3		2.78 ± 0.02^{C}	2.19 ± 0.00C	2.19 ± 0.03^{B}
		Sig.	0.000	0.000	0.000

Averages that do not share a letter in superscripts are significantly different. WHC: water-holding capacity. A.A: antioxidant activity. T.P.: total phenols.

Table 5. Microbiological characterization of sugarcane bagasse powder

Microorganisms	PBCA		Evaluation time in hours (h)		
			0 h	24 h	48 h
Molds and yeasts	M1		2.8x10^{2C}	2.4x10^{3A}	3.7x10^{3B}
	M2		4.8x10^{3B}	2.3x10^{3A}	4.0x10^{3A}
	M3		9.2x10^{2A}	1.2x10^{3B}	3.5x10^{3C}
		Sig.	0.000	0.000	0.000
Escherichia coli	M1		0.0x10	0.0x10	0.0x10
	M2		0.0x10	0.0x10	0.0x10
	M3		0.0x10	0.0x10	0.0x10
		Sig.	sd	sd	sd

Averages that do not share a letter in superscripts are significantly different. sd: No difference.

Conclusions

The different samples of sugarcane bagasse powder presented a characterization of the physicochemical, bromatological, and antioxidant properties of importance for the agri-food sector. Its composition highlights its high value in antioxidant activity, total phenols and crude fiber, which makes this by-product a possible viable alternative as an input in the bakery industry due to its quality of nutritional compounds, however, it is advisable to evaluate toxic substances from fertilizers and insecticides that may have been used in sugarcane crops.

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