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Research article

Physicochemical characterization of the pod husk of *Theobroma cacao* L. of clones CCN51, FEAR5, and FSV41 and its agroindustrial application

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ABSTRACT

In cocoa production, the harvest and postharvest processes tend to generate residues that, if not properly treated or disposed of, become a source of pests or diseases for the crop and the farmer. The residues are environmental contaminants, which are equivalent to 70%–80% of the total fruit (husk, placenta, leachates). In the case of cacao pod husk (CPH), it is hollow form contributes to the accumulation of water or leachates. These residues with no apparent profitable use may have components of agroindustrial interest, such as pectins, cellulose, and starches, in products with high added value. Thus, the physicochemical characterization CPH of clones Castro Naranjal Collection 51 (CCN51), FEDECACAO Arauquita 5 (FEAR5), and FEDECACAO San Vicente 41 (FSV41) is presented to identify different applications such as biopolymers, bioremediation, and renewable energies and their potential biotechnological use in contributing to the circular economy according to the characteristics of each clone. In conclusion, it is important to continue with the research on CPHs of the different clones and to promote the sustainable development of cocoa in the Department of Risaralda, Colombia.

1. Introduction

Cocoa, an evergreen fruit tree belonging to the Malvaceae family with the scientific name *Theobroma cacao* L., requires a tropical climate for its full development, with temperatures between 10 °C and 32 °C, altitudes $<$400 m, and high humidity environments (70%–90%). For this reason, the plantations are usually located between 20°N and 20°S in Ecuador. The plant reaches a size between 4 and 10 m in height. The plant usually starts fruit formation at 3 years, and it is after 8 or 9 years that it reaches its maximum yield and productivity. The fruit has a length of 15–25 cm and a diameter of 8–13 cm. At maturity, the fruit can contain between 20 and 40 beans, which are covered by a white mucilage and are extracted from the cocoa fruit and used as raw material for cocoa production [1].

Cocoa cultivation has been evaluated as a promising alternative for biodiversity conservation due to the fact that its production occurs under shade called “agroforestry,” which allows the use of tree canopies as natural shade [1].

The interest in cocoa cultivation is mainly directed toward the production of chocolate, cocoa powder, and butter from the beans, which are grown in America, Asia, and West Africa (countries in the equatorial zone) [2,3]. West Africa (Ivory Coast, Ghana, Cameroon, and Nigeria) is the largest cocoa producer in the world, but its expansion is compromised by the scarcity of regional forests

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and the protection of the remaining forests as national reserves [1].

Cocoa is one of the fastest-growing crops worldwide, with an estimated world production of 5024 million tons during the 2020–2021 harvest [4]. Cocoa is a family-based crop, and >50 million farmers depend on this crop for their livelihood [5]. Despite cocoa growth, the processing chain (harvesting, fermentation, roasting, threshing, milling, and pulverization) has remained unchanged for 150 years, generating substantial residual biomass in each of the links, such as husk, placenta, and leachates, which causes environmental and phytosanitary issues due to inadequate removal of the plantation and incineration that create environmental burdens, but that could be transformed into bioproducts with added value, such as biofilms, activated carbon, and biofuels [1,3,5,6].

With cacao pod husk (CPH) being the most abundant residue, representing 70%–80% of the dry weight of the fruit, 10,000 Kg of residual husk are generated for each 1000 Kg of grain [1–3,7,8].

CPH is composed of three layers: epicarp, mesocarp, and endocarp. The endocarp is a soft white tissue that protects the beans; the mesocarp is a hard composite structure; the epicarp is a relatively hard structure; and the endocarp is a soft structure, and its color depends on the variety or clone. CPH is a lignocellulosic material composed mainly of cellulose, hemicellulose, lignin, pectins, oils, and waxes [8], lignocellulosic residues that could be exploited in the generation of biomaterials, fertilizers, and renewable energy, in addition to bioactive compounds that can lead to a profitable product with additional income for farmers, promoting economic development [7,9,10].

However, once the fruits have been harvested after ripening, the nuts are opened to extract the kernels together with the mucilaginous pulp for subsequent fermentation, and the husk is discarded directly on the surface, being a source of plant diseases such as black rot of the husk due to the presence of *Phytophthora* spp. This causes an annual yield loss of 20%–30% worldwide, and the husk is an indicator of the phytosanitary health of the fruit because it is the first barrier that pests and diseases must overcome to enter the seeds [1,5].

Agriculture in Colombia is the main economic activity; in the particular case of cocoa, it occupies over 140,000 ha, generating considerable amounts of waste, with approximately 2,100,000 tons of waste in CPH alone by 2021. The most common management is to leave CPH in the field without any treatment or to cut it into smaller pieces to leave it on the ground without any treatment or protection [11].

In the case of Risaralda, approximately 2000 coffee-growing families have been migrating to other crops such as banana, avocado, and cocoa. Cocoa is another alternative for coffee growers, with approximately 1900 ha cultivated [12].

The objective of this study is to characterize CPH by clones, specifically Colección castro Naranjal (CCN51), FEDECACAO Arauquita 5 (FEAR5), and FEDECACAO San Vicente 41 (FSV41), to provide a source of information on products that can be developed based on the physicochemical characteristics of CPH, in addition to bringing reproducibility to the studies by identifying them by clones, given that the existing studies on characterization primarily do not specify the clones under study, which impedes the follow-up of the research and may differ the information between characterizations [13].

2. Materials and methods

2.1. CPH collection and characteristics

To carry out the physicochemical characterization of the CPH, a descriptive and experimental investigation was carried out, where the CPH is obtained from the sampling unit at the Gilberto Pelaez farm of the National Federation of Cocoa Growers, FEDECACAO, located in Marsella, Risaralda, Colombia. The cocoa fruit was selected under the criteria of stable production in the last year to ensure that the cocoa clones, Castro Naranjal Collection (CCN51), FEDECACAO Arauquita 5 (FEAR5), and FEDECACAO San Vicente 41 (FSV41), are identified and not crossed, in addition to being free of phytosanitary diseases.

CPH was determined to characterize CCN51, FEAR5, and FSV41 under the criteria of maturity stage of the cob and higher population density in the Department of Risaralda, Colombia. Subsequently, cocoa trees were randomly selected in the production unit, and the harvest was performed by the person in charge of the production unit under normal conditions. The processes of harvesting, separation of the beans, and removal of CPH were conducted under the methodology of FEDECACAO. Clones FEAR5 and FSV41 have permits from ICA under resolution 4179 and 4185 of December 2, 2014, respectively, and CCN51 is a clone of Ecuadorian origin [12].

Once harvested, CPHs are transported independently in icopor coolers from the Gilberto Peláez farm to the Faculty of Agricultural Sciences and Agroindustry, building 16-C in the alternative laboratories of the Universidad Tecnológica de Pereira.

CPHs were manually selected and cleaned with 3% hypochlorite, separated by clones, cut with a knife to reduce the size with uniform cuts of approximately 5 cm, and dried in a natural convection oven (Thermo Scientific Ref. 5108112) for 48 or 60 h at 65 °C until constant weight, depending on the clone to be treated. Once dried, CPHs were ground and packed in zip-lock bags labeled with the date and type of clone. Finally, CPHs were stored in a cool place until their use for physicochemical analysis in triplicate.

The physicochemical characterization of CPH were calculated using the methods of Association of Official Analytical Chemical. For moisture determination, AOAC 925.10 was adapted using a natural convection oven (Thermo Scientific Ref. 5108112) was used. For pH measurement, AOAC 10.041/84 was adapted using a Tecnal pH meter (Ref. R-TEC-7/1 MP).

For ash, AOAC 923.03 was adapted, in a Thermo Fisher Scientific Thermolyne flask (Ref. FB141 0 M) was used. For the ethereal extract, AOAC 920.39 was adapted used. For the determination of crude fiber (CF) and neutral detergent fiber (NDF), the Velp Scientifica fiber (Ref. SA30540200) equipment was used, which is based on AOAC 978.10 and AOAC 2002.04 adapted. Total sugars were determined based on the spectrophotometric method (Mapada model PV4) with sulfuric acid and phenol with an R2 of 0.989–490 nm [14]. For reducing sugars, a method using DNS spectrophotometry was performed, with an R2 of 0.986–540 nm [15]. For the determination of protein assay, the Bradford method was used, with an R2 of 0.983–540 nm [16]. For the analysis of water retention capacity, the Beauchat method was used [17]. For the determination of oil retention, the Lin and Humbert method was used [17]. For the determination of starch, a qualitative method by color with the reagent lugol was used [18]. Finally, for the determination of cellulose extract, the modified Lubis method was used [19].

3. Results and discussion

Descriptive statistics were used to analyze the results of the data obtained in the laboratory.

3.1. Physicochemical characterization of CPH

Each of the complete *T. cacao* L. cobs was weighed, measured, and opened to count the number of beans per cob, in addition to obtaining the weight of the total number of beans contained in each cob. Subsequently, 10 beans were obtained, and their width, length, and weight were measured. Finally, the placenta and CPH were weighed. The results and images specifying the parts of the measured cob are presented in Table 1, Fig. 1, Fig. 2, and Fig. 3.

Table 2 shows the data of physical tests performed on the CPH of clones CCN51, FEAR5, and FSV41 by other authors for later comparison with the data obtained.

3.2. Cob weight (g)

The weight of the cob analyzed in the laboratory for Castro Naranjal Collection (CCN51) was 863.06 g, consistent with the 856.3 g reported by Báez Daza et al. (2022). As for FEDECACAO Arauquita 5 (FEAR5), the weight of the cob was reported by FEDECACAO. Fedecacao, (2021) reported 613.3 g, which is lower than the laboratory result of 675.74 g, whereas for FEDECACAO San Vicente (FSV41), the reported 732 g is higher than that obtained in the laboratory (Tables 1 and 2, and Fig. 1).

3.3. Grain length (cm)

In the laboratory, a grain length of 27.29 mm was obtained for CCN51, 29.09 mm for FEAR5, and 28.19 mm for FSV41, whereas FSV41 had a greater length of 29.9 mm and CCN51 had a shorter length of 24.72 mm (Tables 1 and 2, Figs. 1 and 2).

3.4. Number of kernels per cob

CCN51 had the highest number of grains contained in an ear with 49 grains, and FEAR5 had the lowest with 40 grains. When compared with the reports of the authors, it was found that CCN51 and FSV41 reported a lower number of grains than those obtained in the laboratory, with 49 and 46, respectively, and a higher number in the case of FEAR5, with 43 grains reported and 40 grains analyzed in the laboratory (Tables 1 and 2, and Fig. 1).

3.5. Grain length (mm)

In the laboratory, a grain length of 27.29 mm was obtained for CCN51, 29.09 mm for FEAR5, and 28.19 mm for FSV41, whereas FSV41 had a greater length of 29.9 mm and CCN51 had a shorter length of 24.72 mm (Tables 1 and 2, Figs. 1 and 2).

3.6. Cob perimeter (cm)

In the laboratory analysis, clone FSV41 presented the largest perimeter with 32.76 cm, followed by clone CCN51 with 31.83 cm,

Table 1
Physical measurements of *Theobroma cacao* L. cob of clones CCN51, FEAR5, and FSV41.

Parameter	CCN51	FEAR5	FSV41
Cob weight (g)	863.06 ± 8.53	675.74 ± 81.78	666.71 ± 32.94
Cob length (cm)	26.82 ± 2.91	26.46 ± 2.79	26.80 ± 3.01
Cob perimeter (cm)	31.83 ± 1.99	29.28 ± 5.11	32.76 ± 1.78
Cob index	10.90 ± 1.56	15.70 ± 3.37	10.60 ± 1.48
No. of grains per cob	49 ± 4.95	40 ± 3.37	46 ± 6.36
Weight of total grains (g)	232.04 ± 17.02	171.72 ± 55.17	226.14 ± 93.24
Grain length (mm)	27.29 ± 6.10	29.09 ± 4.67	28.19 ± 2.50
Grain thickness (mm)	7.73 ± 2.68	7.55 ± 1.62	7.56 ± 0.83
Grain weight (g)	4.82 ± 0.54	4.79 ± 2.20	5.52 ± 0.73
Placenta weight (g)	32.04 ± 7.12	14.15 ± 7.05	36.35 ± 24.97
CPH (g)	637.62 ± 93.26	453.67 ± 35.77	431.12 ± 65.23
Upper CPH thickness (mm)	14.15 ± 2.07	13.18 ± 4.28	12.31 ± 4.80
Center CPH thickness (mm)	13.88 ± 3.09	13.96 ± 4.47	12.21 ± 5.05
Lower CPH thickness (mm)	11.79 ± 2.36	13.04 ± 2.88	11.84 ± 4.69

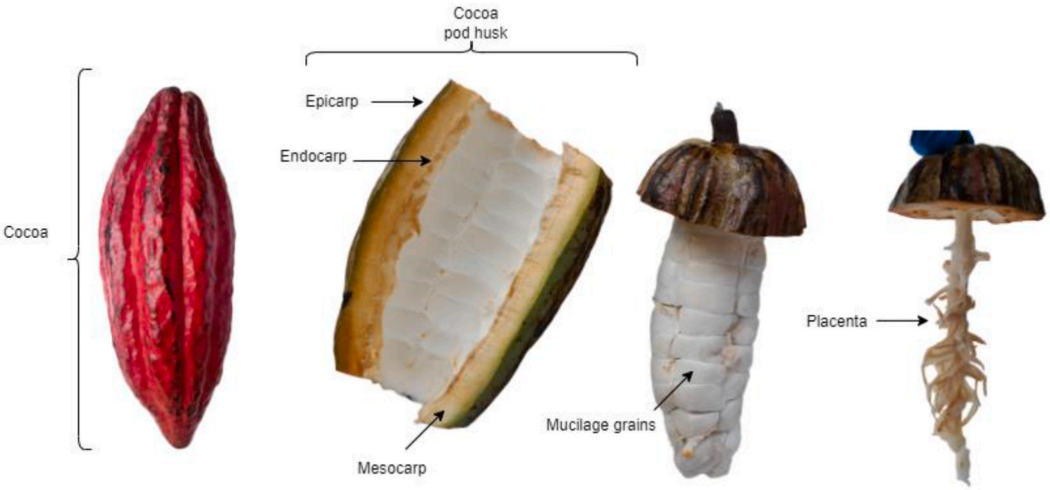

Fig. 1. Parts of the *Theobroma cacao* L. pod husk.

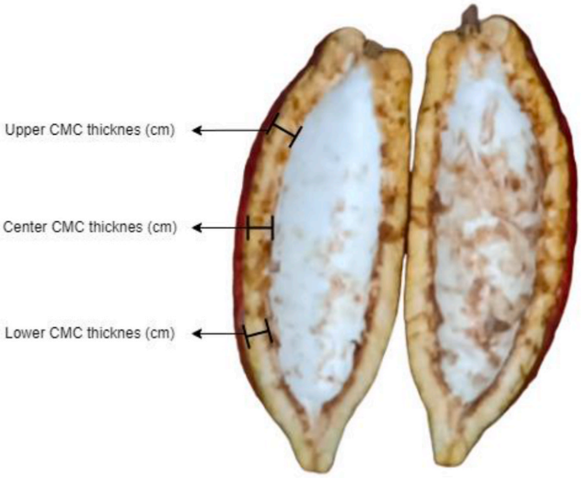

Fig. 2. Location of CPH obtained to measure the top, center, and bottom thicknesses.

and FEAR5 with 29.28 cm (Table 1 and Table 2).

3.7. Cob index

The authors referencing this parameter have a higher result than that obtained in the laboratory, with 15 for CCN51, 17 for FEAR5, and 13 for FSV41, obtaining the data from Perea et al. (2017), compared with 10.9 for CCN51, 15.7 for FEAR5, and 10.6 for FSV41 (Table 1 and Table 2).

3.8. Grain thickness (mm)

The results obtained in the laboratory are lower than those presented by Perea et al. (2017). Subsequently, 7.74 mm was obtained for CCN51, 7.55 mm for FEAR5, and 7.56 mm for FSV41 in the laboratory, compared with 9.1 mm for CCN51, 9.7 mm for FEAR5, and 10.9 mm for FSV41 from FEDECACAO/UIS and 8.8 mm for CCN51 reported by Ospino et al. (2020) (Tables 1 and 2, Figs. 1 and 2).

3.9. Grain weight (g)

The results indicated that FSV41 had the highest grain weight with 5.52 g, followed by CCN51 with 4.82 g, and FEAR5 with 4.79 g (Table 1).

Fig. 3. Measurement of grain length using a digital king foot.

Table 2
Theobroma cacao L. cob physical measurement data of clones CCN51, FEAR5, and FSV41.

Authors/parameter	Clone	Cob weight (g)	Cob length (cm)	Cob index (IM)	No. of grains	Weight of total grains (g)	Grain length (mm)	Grain thickness (mm)
[20](Perea et al., 2017)	CCN51	763.5	21.4	15	–	224.9	25.7	9.1
	FEAR5	613.3	22.4	17	–	160.0	25.7	9.7
	FSV41	732.0	20.7	13	–	234.4	29.9	10.9
[21]Fedecacao, 2021	FEAR5	613.3	–	19	43	–	–	–
	FSV41	732.0	–	14	39	–	–	–
[22](Ospino et al., 2020)	CCN51	–	–	–	–	–	24.7	8.8

3.10. Placenta weight (g)

The measured parameter shows the highest weight for FSV41 with 36.35 g, followed by CCN51 with 32.04 g and FEAR5 with 14.15 g (Table 1 and Fig. 1).

3.11. Weight of CPH (g)

Of the three clones analyzed, the one with the highest CPH weight is CCN51 with 637.62 g, and the one with the lowest weight is FSV41 with 431.12 g (Table 1 and Fig. 1).

3.12. Upper CPH thickness (mm)

CCN51 is the clone with the greatest thickness at the top, with 14.15 mm, followed by FEAR5 with 13.18 mm and FSV41 with 12.31 mm (Table 1 and Fig. 2).

4. Center CPH thickness (mm)

In the central part of CPH, FEAR5 is the clone with the greatest thickness of 13.96 mm, followed by CCN51 with 13.88 mm and FSV41 with 12.21 mm (Table 1 and Fig. 2).

4.1. Lower CPH thickness (mm)

The parameter analyzed is highest for FEAR5 with 13.04 mm, followed by FSV41 with 11.84 mm and CCN51 with 11.79 mm (Table 1 and Fig. 2).

After the physical measurements of CPH, the physicochemical composition of the *Theobroma cacao* L. (CPH) husk was analyzed by clone (Table 3).

For the comparative analysis, 24 research articles or literature reviews on *Theobroma cacao* L. (CPH) husk characterization were used as references (Table 4).

The following is the analysis and comparative results of each of the physicochemical tests performed.

4.2. pH

All clones have a pH of <6, with CCN51 having a pH of 5.50, a value lower than that reported by Jaimes et al. (2017) at 6.2 (Tables 3 and 4).

4.3. Ashes

The ash results ranged from 8.17% to 8.53%, corresponding to CCN51 with the lowest content and FSV41 with the highest. In the present study, CCN51 has a higher result than reported by Hernandez et al. (2019) and Murillo-baca et al. (2020) at 7.76 and 7.1, respectively, but lower than that obtained by Jaimes et al. (2017) at 11.39 (Tables 3 and 4).

4.4. Humidity

A higher percentage of moisture was obtained in clone FSV41 with 85.62% and lower in clone FEAR5 with 81.24%. The results for the three clones (CCN51, FSV41, and FEAR5) are between 80.2% and 89.5%, the range reported by the authors (Tables 3 and 4)

4.5. Ethereal extract

For the ethereal extract, percentages of 1.08%, 1.01%, and 0.70% were obtained for CCN51, FEAR5, and FSV41, respectively. The results obtained for CCN51 are in the range reported by the referenced authors analyzing CCN51 (Tables 3 and 4).

4.6. Crude fiber

The results indicated that the FSV41 clone has the highest percentage (41.69%). Jaimes et al. (2017) and Hernández et al. (2019), authors who characterized CCN51, presented results of 20.52% and 28.13%, respectively; therefore, the value obtained in the laboratory is in this range (Table 3 and Table 4).

4.7. Neutral detergent fiber

For this parameter, FSV41 is the clone with the highest percentage (60.71%), and the lowest is CCN51 (43.87%). Clones CCN51 and FEAR5 are below the data reported by the authors, with the exception of FSV41, which is in the range (Tables 3 and 4).

4.8. Total sugars

Murillo-Baca et al. (2020) reports 45.90% of total sugars for clone CCN51, which is lower than that found experimentally with

Table 3

Results of physicochemical analysis of cocoa pod shells by clone.

Parameter	CCN51	FEAR5	FSV41
pH	5.50 ± 0.012	5.58 ± 0.035	5.74 ± 0.012
Ash (%)	8.17 ± 0.001	8.13 ± 0.002	8.53 ± 0.003
Humidity (%)	84.28 ± 2.941	83.04 ± 7.285	85.62 ± 1.410
Ether extract (%)	1.08 ± 0.008	1.01 ± 0.011	0.70 ± 0.007
Crude fiber (%)	26.42 ± 0.561	39.31 ± 0.035	41.69 ± 0.167
Neutral detergent fiber	43.87 ± 0.186	53.42 ± 0.012	60.71 ± 7E-05
Total sugars (%)	63.72 ± 0.020	44.54 ± 0.031	12.10 ± 0.011
Reducing sugars (%)	11.39 ± 0.019	7.43 ± 0.020	2.88 ± 0.008
Protein (%)	7.90 ± 0.001	6.66 ± 0.001	6.37 ± 0.001
Water holding capacity (CRA) (mL/g)	4.04 ± 0.127	3.31 ± 0.280	3.48 ± 0.483
Oil holding capacity (CRA) (mL/g)	1.17 ± 0.289	1.16 ± 0.289	1.16 ± 0.289
Starch	Negative	Negative	Negative
Cellulose (%)	15.69 ± 3.24	19.31 ± 3.40	15.49 ± 2.89

Table 4

Characterization references of CPH shells of *Theobroma cacao* L. cocoa pods.

Authors/parameter	Clone	pH	%Ash	%Humidity	%ET	%FC	%FDN	%AT	%AR	%P	CRAgua (mL/g)	CRAceite (mL/g)
[23](Lateef et al., 2008)	–	–	11.3	–	4.7	18.30	–	–	–	8.2	–	–
[24](Alemawor et al., 2009)	–	–	–	88.96	–	35.74	59.8	–	–	14.69	–	–
[25](Njoku et al., 2011)	–	–	9.02	–	1.53	59.34	–	–	–	2.09	–	–
[26]. (Syamsiro et al., 2011)	–	–	13.50	–	–	–	–	–	–	–	–	–
[27](Ofori-Boateng & Lee, 2013b)	–	–	10.02	89.5	2.63	–	59.34	–	–	10.74	–	–
[28](Titiloye et al., 2013)	–	–	10.81	–	–	–	–	–	–	–	–	–
[29](Daud et al., 2014)	–	–	12.30	–	–	–	–	–	–	–	–	–
[30](Forero-Nuñez, Jochum, & Vargas, 2015)	–	–	13.21	–	–	–	–	–	–	–	–	–
[31](Laconi & Jayanegara, 2015)	–	–	–	87.10	2.50	55.7	80.7	–	–	8.4	–	–
[32](Esong et al., 2015)	–	–	13.00	87.00	0.60	50	–	–	–	8	–	–
[33](Chun et al., 2016)	–	–	9.02	–	1.53	–	–	17.52	26.38	2.09	–	–
[34](Jaimes et al., 2017)	CCN51	6.2	11.39	82.39	0.71	20.52	–	–	–	6.3	7	3.5
[35](Nguyen & Nguyen, 2017)	–	–	11.42	87.06	0.93	–	–	–	–	2.42	–	–
[36](Lu et al., 2018b	–	–	6.4–8.4	–	1.5–2.0	–	–	32–47	–	7–10	–	–
[37](Campos-Vega et al., 2018b)	–	–	9.10	80.2	1.20	22.6	61	–	–	5.9	–	–
[38](Adeyeye et al., 2019)	–	–	15.50	–	–	14.8	–	–	–	2.19	–	–
[39](Hernández et al., 2019)	CCN51	–	7.76	–	0.25	28.13	–	–	–	5.99	–	–
[40](Vásquez et al., 2019)	–	–	6.7–10.2	–	1.5–2.24	–	–	29.04–32.3	–	4.21–10.74	–	–
[41](Murillo-Baca et al., 2020)	CCN51	–	7.10	–	2.00	–	–	45.9	–	7.9	–	–
[41]Murillo-Baca et al., 2020)	Criollo	–	7.30	–	1.90	–	–	46.3	–	8.1	–	–
[42](de Oliveira et al., 2022)	–	6.18	8.20	–	–	–	–	12.53	4.62	11.7	–	–
[43](Valladares-Diestra et al., 2022)	Forastero	–	9.13	–	–	–	–	–	–	–	–	–

63.72% for the same clone (Tables 3 and 4). The FSV41 clone has 12.1% total sugars, being the lowest content.

4.9. Reducing sugars

For reducing sugars, a higher percentage was obtained for clone CCN51 with 11.39%, and for FSV41, 2.88% was the lowest. The values for clones CCN51 and FEAR5 are in the range reported by the authors, whereas FSV41 is below this (Tables 3 and 4).

4.10. Protein

Protein is between 7.90% and 6.66%, with CCN51 being the clone with the highest content and FSV41 the lowest. Regarding the data reported by Hernandez et al. (2019) and Jaimes et al. (2017) (5.99% and 6.3%, respectively), the data obtained for CCN51 are above these (C).

4.11. Water holding capacity (mL/g)

CCN51 is the clone with the highest water holding capacity at 4.04 mL/g obtained in the laboratory, being lower than that reported by Jaimes et al. (2017) of 7 mL/g of water retention for CCN51 (Tables 3 and 4).

4.12. Oil holding capacity (mL/g)

Clone CCN51 has the highest oil retention capacity at 1.17 mL/g, whereas FEAR5 and FSV41 have the same value at 1.16 mL/g. Of the 24 authors compared, only Jaimes et al. (2017) reported the oil retention capacity of CCN51 at 3.5 mL/g, which is higher than that obtained (Tables 3 and 4).

4.13. Starch

The analysis is negative for all clones. None of the authors compared report this parameter (Table 3).

4.14. Cellulose

The results obtained in the laboratory were 15.69% for CCN51, 19.31% for FEAR5, and 15.49% for FSV41. These values are within the range reported by the references consulted (Tables 3 and 4).

4.15. Agroindustrial application

The characterizations obtained in the laboratory allow us to perform a physical and chemical analysis of CPH and analyze how its content varies depending on the clone. In this way, we can give you a more appropriate and innovative approach to the use you want to address.

An analysis of CPH characterizations obtained in the laboratory could be used in the following.

Animal feed, due to its protein content, which is in a range of 5.40%–8.02%, crude fiber between 26.42% and 41.69%, and total sugars and fats from 0.70% to 1.08%, could be used in formulations of diets as an alternative to optimize production, mainly in ruminants (Table 3) [8,9].

The CPH has an ash content between 8.13% and 8.53%, results obtained in the laboratory (Table 3), which could be used to obtain a low-cost adsorbent for the treatment of contaminated water, having similar properties to charcoal, make it a versatile adsorbent for the removal of contaminants in water sources [44,45]. Another alternative use is to concentrate the potassium hydroxide present in the ash and saponify with oil to produce soaps, obtaining a natural product, less aggressive and more economical product [9].

CPH, being a lignocellulosic material, contains significant amounts of cellulose (15.49%–19.31%), data obtained in the laboratory (Table 3) that can be used in the biopolymer or paper industry [46].

CPH, as lignocellulosic biomass, serves as an energy source for obtaining bioethanol by acid hydrolysis and fermentation, and obtaining biogas by means of thermochemical or biochemical processes [47,48].

5. Conclusions

This study presents the importance of identifying a possible use of CPH since it increases the production of *T. cacao* L. in Risaralda and increases waste as CPH. A physicochemical characterization of CPH allows for the identification of potential uses for the generation of high-value-added products that meet the needs of the sector, contributing to the circular economy and the bioeconomy in Risaralda, Colombia, and the cocoa sector.

A better knowledge of the chemical composition of CPH can support the generation of new strategies for pest and disease management, generating short- and long-term environmental benefits in the value chain. In addition to adding value to waste, CPH can bring economic benefits by developing and selling products, reducing production costs; from the social component, it proposes new sources to generate spaces for the articulation of actors and even spaces for socioeducational growth. This proposal supports a sustainability approach.

From the bibliographic review conducted in this project, we can conclude that 75% of the articles or research do not report the material or clones used for the characterization of CPH, which limits the use, reproducibility, and processes for obtaining future bioproducts.

Owing to its physicochemical characteristics, CPH presents an opportunity for waste reduction, converting to high-value products such as animal feed, energy generation, and biopolymers, among other applications for both the food and nonfood sectors, with added value that contributes to sustainability and optimization of resources, as a relevant source of interest and benefit for farmers, industries, researchers, and consumers.

Ethics declarations

Review and/or approval by an ethics committee was not needed for this study because and the informed consent was not required for this study because this study is part of the development of the objective “Generate a biopolymer based on cocoa waste", financed by the project “Increasing the competitiveness of the cocoa sector through the transformation of agroindustrial waste for innovation and development of nutraceuticals and bioproducts that generate added value to the cocoa bean of the Department of Amazonas". Approved OCAD: BPIN 2021000100226.

Data availability statement

The data associated with the study have not been deposited in a publicly available repository. Data are included in the supplementary material of the article.

CRediT authorship contribution statement

Diana C. Meza-Sepulveda: Visualization, Supervision, Project administration, Methodology, Conceptualization. **Catherine Hernandez:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Conceptualization. **Jorge I. Quintero-Saavedra:** Visualization, Supervision, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Diana Meza Sepulveda reports financial support was provided by Universidad Tecnologica de Pereira, Colombia. Catherine Hernandez Urrea reports financial support was provided by Universidad Industrial de Santander, Colombia. We thank the National Federation of Cocoa Growers FEDECACAO for their help in the sampling process. To the project Development of a Biofilm from Enzymatically Modified Cellulose, Extracted from the Pod Husk of *Theobroma cacao* L. from Risaralda code 11-22-1 of the Universidad Tecnologica de Pereira, Risaralda, Colombia. This research was financed by the project: Increasing the competitiveness of the cocoa sector through the transformation of agro-industrial waste for innovation and development of nutraceuticals and bioproducts that generate added value to the cocoa bean in the Department of Amazonas. Approved OCAD: BPIN 2021000100226.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e28761

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