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Physico-chemical composition and phytochemical screening of cocoa mass purchased commercially in Abidjan (Côte d'Ivoire)

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ABSTRACT

Côte d'Ivoire, the world's leading cocoa producer, nevertheless has a low rate of processing its production. Cocoa mass is one of the products derived from cocoa processing, and its nutritional and functional properties remain poorly documented. This study was conducted to contribute to the valorization of cocoa mass by determining its physicochemical and phytochemical characteristics and identifying its phenolic compounds. To this end, three commercially available samples purchased in Abidjan were subjected to biochemical analyses for physicochemical characterization. The phenolic profile was determined by high-performance liquid chromatography (HPLC). The results revealed significant variability in the physicochemical parameters. The analyses indicated a low moisture content (0.60%), which is a major advantage for long-term storage, a pH (5.8) consistent with well-fermented cocoa, and high levels of fat (53.76%) and carbohydrates (31.95%). The corresponding energy value is equivalent to 661.56 kcal/100 g, indicating a high caloric content. The results also indicate a high fineness (99%) of the cocoa mass. From a phytochemical perspective, HPLC analysis of the cocoa masses enabled the identification and quantification of seven (07) specific phenolic compounds, the major ones being proanthocyanidins (85.33 mg/100 g), epicatechin (118.83 mg/100 g), and catechin (93.33 mg/100 g). Thus, the results of this study confirm that cocoa mass, thanks to its nutritional and functional properties, is a valuable asset for human nutrition, capable of enriching local diets and contributing to food security.

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INTRODUCTION

Agriculture remains one of the most critical sectors for the socioeconomic development of many countries around the world. It ensures food security for populations and serves as a source of financial independence for many producers (World Bank, 2023). Food is a vital need: every individual consumes food to ensure growth, development, and the maintenance of good health. However, when food quality declines, its ability to sustain life is compromised (Thomas *et al.*, 2024). Agricultural crops, which constitute our food supply, are highly diverse. Among them is cacao (*Theobroma cacao* L.), a tropical plant belonging to the Malvaceae family (Whitlock *et al.*, 2001).

Economically speaking, cocoa (Theobroma cacao L.) occupies a prominent position in the agricultural commodities market. It ranks third after coffee and sugar (Beg *et al.*, 2017). From 2021 to 2022, annual global cocoa production for the season was estimated at 4.82 million metric tons, with Africa accounting for 74.5% of that total (ICCO, 2023).

In West Africa, and particularly in Côte d'Ivoire, the national economy is primarily based on cocoa cultivation (Koné *et al.*, 2016). In fact, cocoa alone accounts for approximately 40% of export earnings and contributes 15% to the Gross Domestic Product (GDP) (Koné, 2017). It also generates income for several million producers. Average annual production during the 2022–2023 crop year was estimated at 2.24 millions metric tons. With production accounting for nearly 45% of the global supply (ICCO, 2024), Côte d'Ivoire remains the world's leading cocoa-producing country (Dago and Pei, 2025). Cocoa beans are primarily used in the manufacture of chocolate and cocoa butter (Aprotosoaie *et al.*, 2016).

Côte d'Ivoire has a low processing rate, estimated at about 30% of national production, despite the efforts of processing companies such as CARGILL, BARRY CALLEBAUT, OLAM, and CEMOI (Bockel *et al.*, 2021). As a result, the Ivorian cocoa economy remains export-oriented, primarily in the form of raw beans, thereby limiting the capture of added value.

Among the products resulting from processing is cocoa mass, also known as "cocoa paste" or "cocoa liquor" (Codex Alimentarius, 2016). Thanks to its rheological, functional, chemical, nutritional, and therapeutic properties, cocoa mass is a major ingredient in the chocolate industry (Koné *et al.*, 2016; Foodcom, 2024).

However, despite these optimistic prospects, there is little research on its precise composition in Côte d'Ivoire. Most studies on cocoa have focused on the beans (Sess, 2019; Oussou *et al.*, 2022; Affou *et al.*, 2025). Stakeholders in the cocoa sector and manufacturers would be well advised to promote cocoa mass, especially since its benefits could address numerous health concerns, including malnutrition and physiological balance in children, the sick, and the elderly. This study, which examines the physicochemical composition and phytochemical screening of commercially available cocoa mass purchased in Abidjan, was conducted to assess the quality of the cocoa mass sold in stores.

MATERIALS AND METHODS

Plant material and chemicals

In this study, the plant material used consisted of cocoa mass purchased at the main market in the Abobo district of Abidjan in October 2025. A total of three (03) samples of cocoa mass (M1, M2, and M3) were collected from three different vendors for the study, with one (01) kilogram per sample. All other chemicals and reagents used were of analytical grade.

Determination of water content

The moisture content (TH) of each cocoa mass was determined according to the AOAC method (2000). A 5 g (PE) mass of cocoa mass was weighed in pre-tared porcelain crucibles.

The crucible and sample assembly (M1) was placed in an oven at 105°C until a constant mass was obtained

for 4 hours. After the drying time, the crucible was removed from the oven and placed in a desiccator to cool before being weighed again (M2). The moisture content (TH) was determined using the following equation:

$$TH\ (\%) = \frac{M1 - M2}{PE} \times 100$$

Determination of free fatty acid (FFA) content

The free fatty acid (FFA) content was determined in accordance with ISO 660 :2020.

A 50 mL volume of a previously neutralized diethyl ether/96% ethanol (V/V) mixture was added to a 5 g sample of cocoa contained in a 250 mL Erlenmeyer flask. An indicator (thymol phthalein) was added to this mixture, which was then titrated with a 0.1 mol/L NaOH solution until the indicator turned blue, and the volume (V) was recorded. The free fatty acid content is determined using the following mathematical expression:

$$FFA\ (\%) = \frac{C * V * M}{10 * PE} \times 100$$

Where:

C : is the concentration, in mol/L, of the sodium hydroxide solution ;

V : is the volume, in milliliters, of the sodium hydroxide solution used for the test ;

M : is the molar mass, in grams per mole, of the fatty acid selected for reporting the results;

PE : is the test sample.

pH determination

The pH was determined in accordance with ISO 11289 :1993. Using a pH meter (Mettler Toledo Model S220/230, Switzerland) previously calibrated with pH 4 and pH 7 buffer solutions, the pH value was read directly on the screen after immersing the device's electrode in the liquid cocoa mass.

Determination of fat content

The AOAC (2000) method using the Soxhlet apparatus was employed to extract and quantify total lipids. A flask containing 200 mL of hexane was placed on a hot plate (110 °C).

Meanwhile, a 5-g sample of cocoa mass was placed in a pre-tared WHATMAN cartridge. The apparatus was turned on, and the extraction lasted 8 hours; the flask was then removed from the Soxhlet apparatus and placed in an oven at 105 °C for 1 hour to ensure complete evaporation of the hexane. After evaporation, the flask was reweighed. The lipid content, expressed as a percentage of dry matter, was determined using the following equation:

$$MG\ (\%) = \frac{M2 - M1}{5\ g} \times 100$$

MG : fat content (%);

M1 : mass (g) of the total (sample + flask + hexane) before extraction;

M2 : mass (g) of the total after evaporation of the hexane.

Determination of fineness

The method specified by the International Organization for Standardization (ISO 3310) was used to determine the fineness of the cocoa mass. A 5-gram sample of cocoa mass (M1) was placed in a 75-µm mesh sieve (M0). One liter of hot water (100°C) was poured through the sieve while the cocoa mass inside was stirred. The fat remaining inside the sieve was washed with acetone; the sieve and its contents were then placed in an oven (Memmert Model Bov-D70) at 105°C for 10 minutes. The assembly was removed from the oven, placed in a desiccator to cool for 30 minutes, and weighed (M2). The fineness value is calculated using the following mathematical expression:

$$F\ (\%) = \frac{M2 - M0}{M1} \times 100$$

F (%) : Fineness expressed as a percentage

M0 : mass of the empty sieve, expressed in grams;

M1 : mass of the test sample, expressed in grams;

M2 : mass of the total (sieve + sieve residue), expressed in grams.

Determination of ash content

The ash content was determined using the AOAC (2000) method. A sample weighing two (2) grams of cocoa mass was weighed into a dried porcelain crucible

of mass M1. The sample and crucible assembly (M2) was placed in a muffle furnace (Memmert Model Bov-D70) at 550 °C until a white ash was obtained. The incinerated sample was then placed in a desiccator to cool. The crucible containing the calcined sample was weighed (M3). The ash content (TC), expressed as a percentage of dry matter, is :

$$TC\ (\%) = \frac{M3 - M1}{M2 - M1} \times 100$$

M1 : mass (g) of the empty crucible;
M2 : mass (g) of the assembly (sample + crucible) before incineration;
M3 : mass (g) of the assembly (calcined sample + crucible).

Determination of protein content

Protein content was determined using the Kjeldahl method (AOAC, 2000). One (1) gram of each cocoa mass was heated to 400 °C for 150 min in the presence of a pinch of the catalyst mixture (selenium + potassium sulfate (K_2SO_4)) and 20 mL of 95–97% sulfuric acid (H_2SO_4). The resulting mineralized residue was made up to 60 mL with distilled water. Next, 50 mL of sodium hydroxide solution (40%, w/v) was added. This mixture was brought to a boil in a distillation apparatus. The ammonia released was collected in a volumetric flask containing 10 mL of a mixture of boric acid (4%, w/v) and a mixed indicator (methyl red + bromocresol green) at a pH of 4.4–5.8. The titration was performed using a decimolar solution of sulfuric acid. The mathematical expression for the nitrogen content is given by the following equation:

$$N\ (\%) = \frac{V\ (H_2SO_4) \times N\ (H_2SO_4) \times 14{,}007}{PE \times 1000} \times 100$$

N (%) : Nitrogen content relative to dry matter;
V(H_2SO_4) : Volume of H_2SO_4 in mL;
N(H_2SO_4) : Normality of the added sulfuric acid (0.1 N);
PE : Test sample (g) ;
14.007: Atomic mass of nitrogen.

The protein content, expressed as a percentage of dry matter, was obtained by multiplying the nitrogen content by the conversion factor 6.25.

Total protein (%) = N (%) × 6,25

Determination of total carbohydrate content

This content was calculated by subtraction using the following mathematical expression :

Total carbohydrate (%) = 100 – [TC (%) + protein (%) + MG (%) + TH (%)]

TC : ash content, TH : moisture content, MG : fat content

Determination of energy value

The energy value of the food was determined using the method described by Elenga *et al.* (2016) and the thermal coefficients of Merril and Watt (1973). Thus, for every 100 g of cocoa mass, the energy value was calculated using the following mathematical equation:

Energy value (Kcal) = 9× fat (%) + 4× protein (%) + 4× carbohydrate (%)

1 gram (g) of fat provides 9 kilocalories (kcal);
1 gram (g) of protein provides 4 kilocalories (kcal);
1 gram (g) of carbohydrates provides 4 kilocalories (kcal).

Determination of phytochemicals

Extraction of polyphenols

A 2.5 g sample of cocoa mass was placed in a flask, to which 200 µL of each standard solution was added (para-hydroxyphenylacetic acid in methanol (MeOH or CH3OH) at 4.64 × 10^{-2} mg/mL and/or syringic acid at 9.6 × 10^{-3} mg/mL). The solvent was then evaporated using a rotary evaporator at a temperature below 40°C. Finally, the residue was dissolved in 6 mL of isooctane for SPE analysis.

Solid-phase extraction (SPE)

The extraction was performed using a Supelclean LC-DIOL diol phase cartridge (500 mg/3 mL) from SUPELCO (polymer graft: 2,3-dihydroxypropoxypropyl (7% C)). The resulting residue was conditioned in cartridges containing 6 mL of methanol and 6 mL of isooctane.

After elution, the extract was washed first with 2 × 3 mL of isooctane, then a second time with 4 mL of an isooctane/ethyl acetate mixture (90/10, v/v). The phenolic compound were eluted with 10 mL of methanol, and the entire mixture was transferred to a conical flask. After evaporating to dryness at a temperature below 40°C, the residue (extract) was dissolved in 100 µL of methanol/water (1/1, v/v) at 40°C.

Identification and quantification of specific phenolic compounds

From the phenolic-rich methanolic extracts prepared earlier, 10 µL of each sample was analyzed using an analytical HPLC system (Shimadzu Corporation, Japan) equipped with a binary pump (LC-6A) coupled to a UV-VIS detector (SPD-6A). The phenolic compounds were separated on an ICSep ICE ORH-801 column (25 cm long) at a temperature set to 30 °C. The mobile phase consisted of a 50 mM $NaH_4H_2PO_4$ solution at pH 2.6 (eluent A), an acetonitrile/$NaH_4H_2PO_4$ solution (80 :20, v/v) (eluent B), and 200 mM o-phosphoric acid at pH 1.5 (eluent C). The run time was 70 min at a flow rate of 1 mL/min. The phenolic compounds in the methanolic extract of the cocoa mass samples were identified by comparing their retention times with those obtained by injecting the standard solution containing the phenolic standard compounds under the same conditions.

The concentrations of the individual phenolic compounds in the various samples were estimated using the average peak areas of each standard. Thus, the EC concentration of each phenolic compound in each sample, expressed in mg/100 g of dry matter, is given by the following mathematical relationship:

$$CE = \frac{\text{Aire E} \times CT}{\text{Aire T}}$$

CE : Concentration of each phenolic compound in the sample;
Area T : Average peak area of the standard phenolic compounds ;
Area E : Peak area of the phenolic compound in the sample;
CT : Concentration of the standard phenolic compound.

Statistical analyses

All measurements were performed in triplicate. Statistical analyses of the experimental data were performed using STATISTICA 7.1 software. The means of the dependent variables relevant to the study were compared using Duncan's multiple range test. Statistical significance was set at $p < 0.05$.

RESULTS

Physicochemical composition of cocoa masses

The use of the reference analytical methods presented in this study yielded the results shown in Table 1. The data collected indicate that moisture content varies from one sample to another. They range from 0.54 ± 0.01 to 0.64 ± 0.01%. Furthermore, the minimum and maximum values were observed in samples M2 (0.55 ± 0.01%) and M3 (0.64 ± 0.01%), respectively. The free fatty acid contents in the cocoa mass samples were determined. The results showed variation in the free fatty acid concentration among the different cocoa mass samples. These values ranged from 1.18 ± 0.02% to 5.88 ± 0.01%. The free fatty acid content of sample 2 is statistically different ($p < 0.05$) from that of samples M1 and M3. The cocoa samples M1 and M3 are statistically different from each other ($p < 0.05$). Furthermore, the M2 cocoa mass sample had the highest concentration (5.88 ± 0.01%), while the M1 sample had the lowest (1.18 ± 0.02%). In contrast, the cocoa mass in sample 3 had a free fatty acid content of 1.91 ± 0.02%. Regarding pH, the mean values obtained for the various cocoa mass samples ranged from 5.7 ± 0.1 to 5.8 ± 0.1. Statistical tests did not reveal any significant differences ($p > 0.05$) in pH values among the various cocoa mass samples analyzed.

Fineness was also determined in the various cocoa mass samples analyzed. All concentrations obtained were greater than 99 ± 0.02%. The statistical results show that no significant difference ($p > 0.05$) in fineness was observed among the samples. As for fat content, it varies from one cocoa mass sample to another, but all are below 55%. The fat content of sample M3 is statistically different ($p < 0.05$) from that of M1 and M2. Furthermore, samples M1 and M2

are statistically identical ($p > 0.05$). The highest and lowest concentrations were observed in samples from M2 (54.89 ± 0.0%) and M3 (52.34 ± 0.16%), respectively. Protein contents range from 11.96 ± 0.05 to 12.26 ± 0.11%. Statistical analysis reveals significant differences ($p < 0.05$) in protein content among the three samples analyzed. Sample M3 had the highest protein content (12.26 ± 0.11%) among the cocoa masses analysed. In contrast, the lowest protein content was found in sample M2 (11.96 ± 0.05%). As for carbohydrates, the contents ranged from 30.82 ± 0.03 to 33.06 ± 0.17%. Statistical tests confirm that significant differences ($p < 0.05$) were observed in carbohydrate content among the different cocoa mass samples. The highest content (33.06 ± 0.17%) was observed in sample M3, while sample M2 had the lowest content (30.82 ± 0.03%). The cocoa mass in sample M1 had an average content of 31.99 ± 0.03%. The ash contents of the cocoa masses studied are statistically different ($p < 0.05$) from one sample to another. They range from 1.26 ± 0.03 to 1.71 ± 0.02%. The M3 cocoa mass sample has the highest value (1.71 ± 0.02%), while the M1 sample (1.26 ± 0.03%) has the lowest value. The estimated energy values range from 655.36 ± 0.81 to 666.66 ± 0.56 kcal/100 g of DM. Statistical analysis showed that the energy value of the M2 cocoa mass sample is significantly different ($p < 0.05$) from those of M1 and M3. Furthermore, the statistical results indicate that a significant difference ($p < 0.05$) is observed between the M1 and M3 samples. The highest value (666.66 ± 0.56 kcal/100 g DM) was observed in the M2 cocoa mass sample, while the lowest energy value (655.36 kcal/100 g DM) was recorded in the M3 cocoa mass sample. In contrast, the cocoa mass in sample M1 has an energy value of 662.65 ± 0.33 kcal/100 g of DM.

Table 1. Physicochemical composition and estimated energy value of the cocoa masses studied

Paramters	M1	M2	M3
pH (25°C)	5.8 ± 0.1^{a}	5.8 ± 0.1^{a}	5.7 ± 0.1^{a}
Moisture (%)	0.61 ± 0.02^{b}	0.64± 0.01^{c}	0.54 ± 0.01^{a}
Fat (%)	54.06 ± 0.03^{b}	54.89 ± 0.06^{b}	52.34 ± 0.16^{a}
Ash (%)	1.26 ± 0.03^{a}	1.52 ± 0.02^{b}	1.71 ± 0.02^{b}
Total carbohydrate (%)	31.99 ± 0.03^{b}	30.82 ± 0.03^{a}	33.06 ± 0.17^{c}
Protein (%)	12.06 ± 0.05^{b}	11.96 ± 0.05^{a}	12.26 ± 0.11^{b}
Free fatty acid (%)	1.18 ± 0.02^{a}	5.88 ± 0.01^{c}	1.91 ± 0.02^{b}
Fineness (%)	99.27±0.02^{a}	99.77±0.02^{a}	99.27±0.02^{a}
Energy value (Kcal/100 g)	662.65 ± 0.33^{b}	666.66± 0.56^{c}	655.36 ±0.81^{a}

For each parameter, the means ± standard deviations in the rows, which are denoted by different letters, are statistically different from one another at the p ≤ 0.05 level according to Duncan's test ; M1 : cocoa mass 1 (sample 1) ; M2 : cocoa mass 2 (sample 2) ; M3 : cocoa mass 3 (sample 3).

Identification of phenolic compounds

HPLC analysis of the cocoa masses enabled the identification of specific phenolic compounds. These compounds were identified by comparing their retention times with those obtained by injecting a standard solution containing standard phenolic compounds under the same conditions. Fig. 1 shows the chromatographic profiles of the phenolic compounds in the analyzed cocoa masses. Seven (07) phenolic compounds were identified in the cocoa masses. These include proanthocyanidin, catechin, epicatechin, quercetin, syringic acid, cinnamic acid, and benzoic acid. Among these identified phenolic compounds, several classes of polyphenols were distinguished, notably flavonoids (catechin, epicatechin, quercetin), condensed tannins (proanthocyanidins), and phenolic acids represented by cinnamic acid, benzoic acid, and syringic acid. The results showed that proanthocyanidins and epicatechin are present in all three cocoa masses samples. Catechin and cinnamic acid were identified in cocoa mass samples M1 and M2. Furthermore, quercetin was identified in cocoa mass samples M2 and M3. In contrast, the analyses revealed that syringic acid and benzoic acid were present only in cocoa mass sample M3.

With regard to the retention times of specific phenolic compounds, the values ranged from 2.90 to 7.70 minutes. The results indicated that the shortest

retention time was observed for proanthocyanidin (2.90 minutes), while benzoic acid had the longest retention time (7.70 minutes). However, epicatechin, syringic acid, catechin, cinnamic acid, and quercetin exhibited retention times of 3.20 minutes, 4.60 minutes, 5.70 minutes, 6.50 minutes, and 7 minutes, respectively.

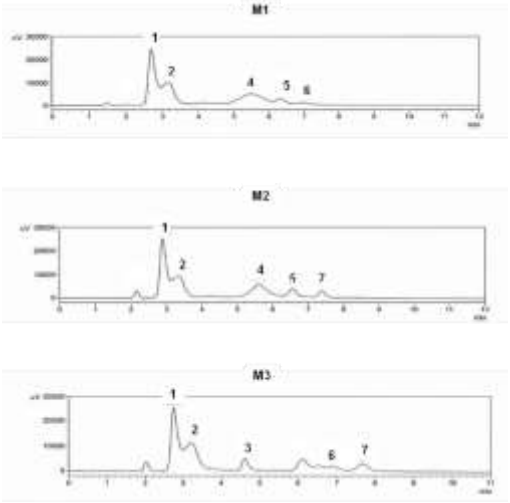

Fig. 1. Chromatographic profile of phenolic compounds in cocoa masses

1 (Proanthocyanidin: RT = 2.90 min), 2 (Epicatechin: RT = 3.20 min), 3 (Syringic acid: RT = 4.60 min), 4 (Catechin: RT = 5.70 min), 5 (Cinnamic acid: RT = 6.50 min), 6 (Quercetin: RT = 7 min), 7 (Benzoic acid: RT = 7.70 min) ; M1 : cocoa mass 1 (sample 1) ; M2 : cocoa mass 2 (sample 2) ; M3 : cocoa mass 3 (sample 3).

RT : Retention time

The specific phenolic compounds identified in the various cocoa mass samples tested were quantified. Table 2 presents the concentrations, expressed in mg/100 g of dry matter, of the various phenolic compounds found in the cocoa masses studied. This table shows that syringic acid and benzoic acid were identified only in the M3 cocoa mass sample. The concentrations of syringic acid and benzoic acid were 3.01 ± 0.02 mg/100 g and 0.06 ± 0.01 mg/100 g, respectively. The proanthocyanidin contents in the various cocoa samples were determined. Variation in the content of this phenolic compound was observed among the different samples. The contents range from 56.52 ± 0.44 to 110.95 ± 0.04 mg/100 g. The proanthocyanidin content of sample M3 is statistically different ($p < 0.05$) from that of samples M1 and M2. Samples M1 and M2 are also statistically different ($p < 0.05$) from one another. Furthermore, sample M3 has the highest proanthocyanidin content (110.95 ± 0.04 mg/100 g), while sample M1 has the lowest (56.52 ± 0.44 mg/100 g). In contrast, sample M2 has an average proanthocyanidin content of 88.52 ± 0.06 mg/100 g. As for catechin, the levels range from 89.86 ± 0.11 to 97.81 ± 0.18 mg/100 g. Although it was not detected in all samples, statistical tests confirm that significant differences ($p < 0.05$) were observed in catechin content among different cocoa mass samples. The highest content (97.81 ± 0.18 mg/100 g) was observed in sample M2, while sample M1 had the lowest content (89.86 ± 0.11 mg/100 g). For quercetin, the average levels ranged from 0.45 ± 0.01 to 1.09 ± 0.01 mg/100 g. Statistical analysis revealed a significant difference ($p < 0.05$) among the samples.

The results indicate that sample M3 had the highest quercetin content (1.09 ± 0.01 mg/100 g), while the lowest content was observed in sample M2. The epicatechin content in the various cocoa samples studied ranged from 79.74 ± 0.22 to 167.8 ± 0.40 mg/100 g. The epicatechin content of cocoa sample M3 was significantly different ($p < 0.05$) from that of cocoa samples M1 and M2. Samples M1 and M2 are statistically different ($p < 0.05$) from one another. As for the M3 cocoa mass sample, its epicatechin content was the highest, with an average of 167.8 ± 0.40 mg/100 g, whereas the M1 cocoa mass had the lowest content, with an average of 79.74 ± 0.22 mg/100 g. Cocoa sample M2, meanwhile, recorded an average concentration of 108.95 ± 0.06 mg/100 g. Cinnamic acid was also quantified in the various cocoa masses samples studied. Cinnamic acid levels ranged from 15.38 ± 0.02 mg/100 g to 31.84 ± 0.02 mg/100 g. Statistical analysis of the cinnamic acid levels revealed significant differences ($p < 0.05$) among the samples, although this compound was detected in only two samples (M1 and M2). Sample M2 had the highest content (31.84 ± 0.02 mg/100 g). In contrast, the lowest cinnamic acid content was found in sample M1 (15.38 ± 0.02 mg/100 g).

Table 2. Phenolic compound content of cocoa masses

Phenolic compound (mg/100 g)	Retention time (min)	M1	M2	M3
Syringic	4.60	nd	nd	3.01 ± 0.02[a]
Proanthocyanidin	2.90	56.52 ± 0.44[a]	88.52 ± 0.06[b]	110.95 ± 0.04[c]
Catechin	5.70	89.86 ± 0.11[a]	97.81 ± 0.18[b]	nd
Quercetin	7	nd	0.45±0.01[a]	1.09 ± 0.01[b]
Epicatechin	3.20	79.74 ± 0.22[a]	108.95 ± 0.06[b]	167.8 ± 0.40[c]
Benzoic acid	7.70	nd	nd	0.06 ± 0.01[a]
Cinnamic acid	6.50	15.38 ± 0.02[a]	31.84 ± 0.02[b]	nd

For each parameter, the means ± standard deviations shown in the rows, denoted by different letters, are statistically different from one another at the $p \leq 0.05$ level according to Duncan's test; M1 : cocoa mass 1 (sample 1) ; M2 : cocoa mass 2 (sample 2) ; M3 : cocoa mass 3 (sample 3) ; nd : not determined.

Furthermore, this study generally shows that proanthocyanidin, catechin, and epicatechin are the most abundant compounds in the M1, M2, and M3 cocoa masses samples. In contrast, quercetin and syringic acid are present in the cocoa samples at low levels. Among the identified and quantified flavonoids, epicatechin predominates, with concentrations ranging from 79.74 ± 0.22 to 167.8 ± 0.40 mg/100 g. Proanthocyanidin (56.52 ± 0.44 and 110.95 ± 0.04 mg/100 g) is the only condensed tannin present in the analyzed cocoa mass samples. As for phenolic acids, cinnamic acid stands out as the compound that is also abundant in the samples, with concentrations ranging from 15.38 ± 0.02 to 31.84 ± 0.02 mg/100 g. Benzoic acid is the phenolic acid present in the cocoa mass samples studied, with a low concentration (0.06 ± 0.01 mg/100 g).

DISCUSSION

The physicochemical and phytochemical parameters of the cocoa mass were determined. The phenolic profile of the cocoa masses was also evaluated.

The experiments conducted showed that the moisture content of the cocoa mass samples was very low, ranging from 0.54 ± 0.01 to 0.64 ± 0.01% ; this suggests that the cocoa beans used to produce the cocoa masses were well dried. Such a low moisture content in these cocoa masses would allow for their long-term preservation and stability. Indeed, it is well established that a high moisture content in food products promotes microbial growth and enzymatic activities that accelerate their spoilage (Aremu *et al.*, 2009).

The pH values are, on the whole, statistically identical across the various cocoa masses studied. These values range from 5.7 ± 0.1 to 5.8 ± 0.1 and indicate an acidic pH. Indeed, an acidic pH is believed to be responsible for a high accumulation of organic acids in cocoa beans (Afoakwa, 2010). Conversely, a pH that is too high (> 6) could indicate incomplete fermentation, limiting the diffusion of acids and the degradation of polyphenols, resulting in cocoa that is less aromatic and bitter. The pH values recorded in this study are consistent with the optimal range ($5 \leq$ pH ≤ 5.8) described for well-fermented cocoa according to Camu *et al.* (2007).

As for ash content, it varies statistically from one cocoa mass to another, with levels ranging from 1.26 ± 0.03 to 1.71 ± 0.02%. This variation is thought to be due to either the harvest site (the soil), the season, or the climate. The values obtained in this study are lower than those reported by Kongor *et al.* (2016) and Daverio (2005) for cocoa nibs and cocoa mass, with respective values of 2.6 to 4% and 3%.

Fineness is an important parameter as a quality criterion for cocoa mass. Indeed, it provides information on the quality of the grinding of the cocoa mass. This study revealed concentrations exceeding 99%, indicating controlled grinding of the beans and good fineness of the cocoa masses studied.

As for free fatty acids (FFA), the concentrations ranged from 1.18 ± 0.02% to 5.88 ± 0.01% and varied from one cocoa mass to another. This variation could be explained by the fermentation process.

Furthermore, drying is of crucial importance for the final quality of the cocoa beans. The drying process must be slow to promote the evaporation of volatile acids such as acetic acid (Zahouli *et al.*, 2010; Saltini *et al.*, 2013).

In fact, rapid drying of cocoa leads to an accumulation of acidity in the beans (Kongor *et al.*, 2016). Prolonged storage under humid conditions can also cause an accumulation of free fatty acids. Furthermore, a high percentage of broken beans would increase this acidity. These practices can result in a free fatty acid content exceeding 1.75%, which is the legal limit for cocoa butter in the EU (Directive 2000/36/EC) (EU, 2000) and in the Codex standard for cocoa butter (86-1981, Rev. 1 2001) (Codex Alimentarius, 2001).

Regarding protein content, a notable variation was observed, with moderate values ranging from 11.96 ± 0.05 to 12.26 ± 0.11%. This variation is believed to be related to the harvest region, the type of cocoa, the harvest period, and the fermentation and/or drying of the cocoa beans used to produce the cocoa mass. This moderate protein content plays an important role in the aroma of the cocoa mass. In fact, while not all biochemical reactions occurring during fermentation have been identified, they do initiate the breakdown of proteins in the beans into amino acids and peptides—components that serve as precursors to cocoa aromas, which are subsequently released during roasting (Daverio, 2005; Affou *et al.*, 2025). The results obtained in this study are largely consistent with those of previous studies, in which the protein content ranged from 10 to 18% (Touron, 2024; Affou *et al.*, 2025). Consequently, these cocoa masses could be useful in preventing malnutrition.

With regard to lipids, the levels in the analyzed cocoa masses ranged from 52.34 to 54.89% on a dry matter basis. The results obtained in this study are consistent with those reported by Daverio (2005) in his research on cocoa mass, which recorded a lipid content of 54%. The lipid content influences the texture, fluidity, and stability of chocolate and other products derived from cocoa beans. Thus, the analyzed cocoa masses, characterized by their high lipid content, are raw materials of choice for the chocolate, cosmetics, and pharmaceutical industries, due to the high yield of cocoa butter they provide (Daverio, 2005; Touron, 2024).

Indeed, the cocoa bean, from which cocoa mass is derived, has a high concentration of saturated fatty acids (palmitic acid and stearic acid) and monounsaturated fatty acids (oleic acid), and a lower content of polyunsaturated fatty acids (linoleic acid) (Salazar *et al.*, 2020).

The cocoa masses studied were found to be rich in carbohydrates, with levels equivalent to 30%. These results are consistent with those reported by Touron (2024) and Daverio (2005), according to whom the carbohydrate content of cocoa beans and chocolate generally ranges between 30 and 44%. Carbohydrates and lipids are the major components of cocoa mass.

These relatively high carbohydrate contents in cocoa mass provide evidence that it is a source of energy. Furthermore, it is known that the carbohydrates in cocoa mass comprise various groups, including monosaccharides (glucose and fructose), oligosaccharides (sucrose), and storage polysaccharides (starch, cellulose) (Daverio, 2005; Ehrlich, 2023).

When considering the estimated energy value, cocoa mass appears to be a good source of energy, as the values reported are high, ranging from 655.36 ± 0.81 to 666.66 ± 0.56 kcal/100 g of dry matter. These high energy values are likely due to the high carbohydrate and fat contents, which indicate a high caloric density. This high caloric content gives these cocoa masses promising potential for combating energy malnutrition. The high energy density of these cocoa masses makes them suitable for food formulations designed to meet significant caloric needs, provided consumption is monitored. The nutritional data reported in the Ciqual 2025 database indicate an average energy value of approximately 591 kcal/100 g

for dark chocolate containing about 70% cocoa solids, which is lower than the values obtained for the cocoa masses analyzed in the present study (Du Chaffaut *et al.*, 2025).

It is well established that cocoa beans are rich in antioxidants (Caligiani *et al.*, 2016). In fact, they contain flavonoids (catechin and epicatechin), as well as procyanidins, which, after being absorbed in the intestine, circulate in the blood plasma where they neutralize free radicals, increase plasma antioxidant capacity, and protect LDL lipoproteins from oxidation (Aprotosoaie *et al.*, 2016). Most of the phenolic compounds identified in the cocoa masses analysed were detected in cocoa beans and in chocolate (Ehrlich, 2023). In terms of the content of specific phenolic compounds, catechin, epicatechin, and proanthocyanidin are the major compounds identified in the cocoa masses analyzed by HPLC. Elwers *et al.* (2009) and Ehrlich (2023) also reported significant levels of these phenolic compound in cocoa beans and chocolate. According to Caligiani *et al.* (2016), three groups of phenols are present in cocoa beans: proanthocyanidins (approximately 58%), catechins (approximately 37%), and anthocyanins (approximately 4%). It is well established that phenolic compounds improve digestion and help combat cardiovascular disease and oxidative stress (Daverio, 2005; Affou *et al.*, 2025). Thus, consuming these cocoa masses could contribute to improved human health.

CONCLUSION

The objective of this study was to determine the physicochemical parameters of the cocoa mass and to evaluate its phenolic profile.

Overall, the results show that the cocoa masses tested have good levels of carbohydrates (30.82 ± 0.03 to 33.06 ± 0.17%) and fat (52.34 ± 0.16 to 54.89 ± 0.0%), making them a good source of energy. Consuming these cocoa masses would be beneficial for consumers as it would allow them to engage in more intense physical activity for longer periods. They also constitute a source of energy suited to the needs of children and the elderly. Furthermore, the results for the cocoa mass revealed a moderate protein concentration (11.96 ± 0.05 to 12.26 ± 0.11%), which plays an important role in the aroma of cocoa. Furthermore, seven (07) phenolic compounds were identified in the M1, M2, and M3 cocoa masses, the most prevalent of which are proanthocyanidin, catechin, and epicatechin.

The results of this study contribute to achieving food security in Côte d'Ivoire, since cocoa mass is the primary ingredient in the production of chocolate consumed in the country. Thus, cocoa mass is a valuable asset for human nutrition, capable of enriching local diets and contributing to food security. Consequently, the consumption of these cocoa masses could contribute to improved human health.

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