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Research Article

Effects of Fermentation Periods and Drying Methods on Postharvest Quality of Cocoa (*Theobroma Cacao*) Beans in Ghana

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Cocoa (*Theobroma cacao*) contributes significantly to Ghana's GDP and has made Ghana a recognized leader in the cocoa industry. However, there are myriad problems associated with Ghana's cocoa bean quality. One such problems stems from farmers paying less attention to the required postharvest activities (fermentation and drying) which contributes significantly to bean quality losses. This study investigated the effect of the duration of the traditional heap fermentation period and different drying methods: solar biomass hybrid dryer (SBHD) and traditional sun drying method (TSDM) on the bean quality of two cocoa varieties (hybrid cocoa and Amazonia). Quality attributes of cocoa beans such as pH, moisture content, fat content, crude protein, free fatty acids, phenolic contents, colour, and bean size were examined. The statgraphics statistical tool was used to analyse data and the least significant difference (LSD) was used to compare treatment means. Purple beans incidence was observed to be lower in hybrid with a value of 21.90% in the solar biomass hybrid dryer after 5 days of fermentation. Hybrid recorded the highest flavonoid value of 6069.74 mg QE/g DW in the traditional sun drying after 7 days of fermentation. Hybrid as well recorded the highest total phenolic value of 711.44 mg GAE/g DW in the solar biomass hybrid dryer under 5 days of fermentation. Results also indicated that using the solar biomass hybrid dryer resulted in the best moisture content removal and was very efficient compared with the traditional sun drying method in ensuring high-quality beans per international market standards. Cocoa beans dried under SBHD had the overall highest purity and were of better quality compared to those dried directly in the sun. There were no significant differences ($p \leq 0.24$) in percentage purity among the cocoa samples studied.

1. Introduction

Cocoa has played a pivotal role in Ghana's economy and has been a major source of revenue for the country since independence [1]. In 2007, cocoa contributed about 20% to the country's revenue on annual export [2]. The report also revealed that cocoa production alone employs about 3.2 million people nationwide, taking care of about 800,000 families in Ghana. In 2005, cocoa provided an income earning of US$ 945 million, accounting for 30% of the foreign exchange earnings of Ghana ICCO [2]. Cocoa is the number one agricultural income earner with a source of employment for 29% of the farming population [3] and 60% of total employment including all peripherals of the agricultural sector, with a total contribution of about 35% to the country's gross domestic product (GDP) [2].

Ghana faces problems with quality cocoa beans because of unnecessary competition among license-buying companies to aggregate more beans than others, coupled with the desire for quick money by cocoa farmers. The eagerness of farmers to send their produce to the license-buying companies for money and other incentives, they tend to fast-track the postharvest activities rather than abandon the proper fermentation and drying practices and spend less time on these practices. Deterioration of cocoa quality and reduction in quantity are the results of these acts of farmers and license-buying companies not adhering to the recommended postharvest activities.

The unique flavour and quality of cocoa have contributed to popularity of its products like chocolate [4]. The unique flavour and the quality of cocoa are obtained during its primary processing stage, that is, during the fermentation and drying of the cocoa beans. It must be noted that if the cocoa beans are not processed well, the beans become bitter without any flavour. Therefore, there is the need to adopt a proper fermentation method [4]. The fermented beans are subsequently subjected to drying to remove the surrounding mucilage and contaminated microorganisms, and to reduce the moisture content to the optimum. For this effect, the traditional sun drying method is usually used, but it poses some threat to the beans. By using this method (traditional sun drying), the quality of beans obtained is dependent on good weather, subjected to dust contamination and considerable quantity consumption of the beans from both birds and animals. Generally, drying of the beans reduces the moisture content to an optimum of about 7% to 7.5% to prevent over-fermentation, mould contamination, and bean damage during storage. Furthermore, this significant stage also plays a role in reducing bitterness, astringency, and acidity, as well as in the acquisition of the characteristic flavour and brown colour [5].

Despite being recognized with the premium leadership in the industry, the cocoa sector of Ghana faces problems of quality as a result of competition among license-buying companies and the desire for quick money by farmers. When farmers abandon the proper fermentation and drying practices by spending less time on postharvest activities (i.e., fermentation and drying by traditional methods), deterioration of cocoa quality and a reduction in quantity are observed, culminating in the sale of poorly dried beans. The fermentation period is usually 7 days for the beans to assume a dark chocolate colour and flavour. This situation has the potential of depriving the country of the premium it earns, which can ruin the industry with less demand for Ghanaian cocoa beans and disastrous economic implications.

The drying process begins immediately after cocoa beans have properly fermented. Cocoa beans must be dried to about 55% to 7% moisture content level to be safe for storage. According to Fagunwa et al. [6], an intermittent dryer is ideal for drying the beans to a safe moisture level (3.6%, w.b) within 72 hours. Drying as a postharvest practice also influences overall market quality, thus, the development of flavour, final bean acidity, mouldiness, and the presence of off-flavour in the beans. Under adverse weather conditions, the slow rate of sun drying results in mouldiness and the development of off-flavour [7]. The beans are also more likely to be adulterated by dust and other debris during sun drying. Beckett [8] argues that, even though artificial drying of fermented beans mostly leads to the fast drying of the cocoa beans by taking away moisture from them, the continuous forced air drying leads to the breaking of cocoa beans and increases the bitterness of the beans. It also causes the cocoa beans to wrinkle [9]. Many authors, with an emphasis on reducing acidity, have investigated the causes of the inferior quality of artificially dried beans. Chocolate flavour development, which begins during fermentation, continues during drying and the mediating enzymes are destroyed by temperature of over 60°C [10]. The cocoa beans, when properly dried, have a moisture content that ranges between 6–8% and are low in acid concentration and, hence, reducing the bitterness of the beans and usually having a chocolate brown colour [11]. The removal of moisture from cocoa beans is faster in the artificial method than in the natural sun drying method [10]. The difference in the drying rate may be attributed to several factors, such as temperature, the time the bean is exposed to heat, the rate at which moisture evaporate and the nature of air flow in the beans [12].

In view of that, the sustainability of the industry is inevitable. Consequently, using alternative fermentation and drying methods for shorter postharvest activities in achieving the same quality dried cocoa beans with the optimum moisture content and Ghanaian cocoa characteristics (reduced bitterness, astringency, and acidity with the acquisition of the characteristic flavour and brown colour) is vital. In this research, we assessed the effect of different fermentation periods and drying methods on the postharvest quality of cocoa beans using two varieties of cocoa (hybrid cocoa and Amazonia).

2. Materials and Methods

2.1. Study Area. The experiment was conducted during the rainy season (this is the period where rainfall is frequent, coupled with high relative humidity and low temperature). These conditions are required for the fermentation and drying of cocoa beans. Also, this is the period that fermentation and drying are done in the study area) from April to October 2017 in Ntinanko, a predominant cocoa community in the Bekwai Municipality of the Ashanti Region of Ghana. The district is within longitudes 1°00′W and 1°35′W and Latitude 6°00′N and 6°30′N. The District shares boundaries to the north with Bosomtwe District, to the south with Adansi North District, to the east with Bosome-Freho District and to the west with Amansie West and Amansie Central Districts [13].

2.2. Source of Experimental Material. Amazonia and hybrid varieties of cocoa were harvested at their ripened/mature stage from a cocoa farm in the study area (Ntinanko). The pods were broken, and the beans were scooped out of the pods for fermentation using the traditional heap fermentation method.

Figure 1: Cocoa beans undergoing sun drying in the study.

2.3. Experimental Design. The experiment was conducted using a $2 \times 4 \times 2$ factorial completely randomized design with factors: cocoa variety (Amazonia and hybrid), fermentation period (4, 5, 6, 7 days), and drying method (solar biomass hybrid drying and traditional sun drying for 6 days).

2.4. Cocoa Bean Fermentation. Two varieties of cocoa (Amazonia and hybrid) beans were fermented using the traditional heap fermentation method [14]. The cocoa pods were broken and the beans scooped out into a heap on the leaves of the banana plant. Heaps of the varieties, thus, Amazonia and hybrid, were then divided into 4 heaps. This was to ensure that there were batches that were subjected to 4, 5, 6, and 7 days of the fermentation process.

2.5. Drying of Fermented Cocoa Beans

2.5.1. Solar Biomass Hybrid Drying (SBHD). The dryer operates on two modes: insular mode and hybrid mode.

Insular mode: during the insular mode of operation, only solar energy from the sun. Solar radiation is engrossed by the product and the internal surfaces of the drying chamber, generating heat, thus, increasing the temperature of the crop and enclosure [15]. Moisture evaporates from the sample and leaves chamber with warm air.

Hybrid mode: in addition to solar radiation, a biomass furnace is used to heat air and blown into the dryer to help dry produce.

2.5.2. Traditional Sun Drying Method (TSDM). Fermented cocoa beans were dried on bamboo mats placed on a raised platform, as shown in Figure 1. The fermented beans of 1 kg were then spread evenly on an area of 10 cm^2 on the bamboo mat. In order to prevent the condensation of dew on the beans, a black polythene sheet was used to cover the drying beans between the hours of 6pm to 6am daily.

2.5.3. Temperature and Relative Humidity Monitoring during Cocoa Beans Drying. Drying conditions (temperature and relative humidity) inside the dryer and the drying area were monitored during the drying of cocoa beans using the Tinytag data logger TGP-4017(Gemini data loggers, Chichester, UK).

2.6. Physical Analysis

2.6.1. Cut Test. Physical qualities such as colour, bean size, and moisture content were determined by physical inspection of the cocoa beans. The moisture meter (aqua buoy) was used to measure the moisture content of the cocoa beans. The cut-test was used to assess the internal colouration and other levels of defects in cocoa beans. The cut-test is one of the very widely known methods to evaluate the internal colouration of cocoa beans. It comprises randomly cutting lengthwise 300 cocoa beans taken from a sample, next by inspection and recording defects (purple, mouldy, insects, germination-damaged and slatty beans). The test has a merit of not requiring specialized equipment (simply a knife or Magra cutter).

2.6.2. Laboratory Analysis. The laboratory analyses of the dried cocoa bean samples, which included pH of the beans, fat content, free fatty acids, protein, flavonoids, and total polyphenols were conducted at the Applied Radiation Biology Centre of the Radiation and Medical Sciences Research Institute (RAMSRI) of the Ghana Atomic Energy Commission.

2.6.3. Determination of pH. Calibration was done at 20°C using two buffers (pH 4.00 and 7.00). Forty (40) grams of powdered cocoa beans were weighed into a 100 mL beaker. While stirring slowly, 60 mL of boiling distilled water from a graduated cylinder was added to the ground nib. The mixture was left to cool in a cold bath while it was stirred occasionally. The pH was measured when the suspension had cooled to 20°C.

2.7. Proximate Analysis

2.7.1. Determination of Fat Content. Cocoa beans sample was ground and mixed thoroughly. Two (2) grams of the sample was weighed and placed on a filter paper fold. In other to hold the sample in place, the filter paper was folded up. To achieve even distribution, a piece of cotton is placed on top of the solvent and allowed to drop on the sample. The sample packet was then placed in the butt tubes of the Soxhlet extraction apparatus. The extraction flask was then put in an oven with a heat of about 110°C for approximately 5 minutes. The flask was removed from the heat and allowed to cool for some time. The flask was then weighed for the second time. The fat was extracted with petroleum ether for 2–3 hours without interruption by gentle heating, and allowed to cool, and the extraction flask dismantled. The ether was evaporated on a water bath until no odour of ether remained. It was then cooled to room temperature. The extraction flask and its extract were re-weighed and the weight recorded.

2.7.2. Determination of Moisture Content (%MC). A moisture can was weighed. Two (2) grams of granular sample was weighed and added to the moisture can. This was allowed to dry overnight in an air oven at 110°C for 24 hours. The can and the sample were cooled in desiccators and re-weighed.

2.7.3. Determination of Crude Protein. Two (2) g of dried cocoa beans were weighed and transferred to a 500 mL digestion flask. A spoonful of $CuSO_4$-$NaSO_4$ and 15–25 mL of H_2SO_4 were added to the content in the flask. Boiling chips were added and the sample was digested until a colourless solution was achieved. A 100 mL conical flask containing 25 mL of boric acid solution with a few drops of mixed indicator was placed, and 50 mL of 40% sodium hydroxide solution was added to the test solution in the apparatus. The ammonia was distilled and collected with boric acid. 100 mL of the distillate was collected. The solution was titrated against the standard acid until the first appearance of pink colour (end-point). A reagent blank with an equal volume of distilled water was run and the titration volume was subtracted from that of the sample titration volume. The N content of the sample was calculated as follows:

$$(N_T) = (ml\,Hcl\,blank) \times 14.01 \times Normality \div 10 \times weight\,of\,sample, \quad (1)$$

where (N_T) = Total Nitrogen.

This implies that, the percentage of Crude Protein (% CP) = 6.25 (which is the Protein factor) × Total Nitrogen (N_T).

2.7.4. Determination of Free Fatty Acids (FFA). Ethanol (95%) was added to the mined fat until a uniform mixture was obtained. The mixture was then titrated to 0.1 M using phenolphthalein as an indicator. The rate of titration was recorded.

It was calculated using the following formula:

$$\%FFA = 100 \times N \times F \times V \div 1000 \times SW\ (AOAC, 2012) \quad (2)$$

[16] where V = NaOH volume required. N = NaOH normality and F = equivalent weight of FFA expresses in equivalents of oleic acid and; SW = sample weight.

2.8. Polyphenolic Analyses

2.8.1. Determination of Total Flavonoid Content. The aluminium chloride colourimetric assay method [17–19] was employed to evaluate overall flavonoid content using Quercetin as a standard. An aliquot of 500 μL extract was mixed with the following, 1500 μL of 99.9% ethanol, 100 μL of 1 M potassium acetate, 100 μL of 10% aluminium chloride and 3000 μL of distilled water. The resultant mixture was incubated for 30 minutes at room temperature and corresponding absorbance measured at 415 nm. A standard calibration curve was constructed using Quercetin standard solutions of 25 μg/mL, 50 μg/mL, 75 μg/mL, 100 μg/mL and 125 μg/mL each time the samples were analysed. 500 μL of each standard was treated in the same manner as the samples and a calibration linear regression equation of $y = 141.9x$ was obtained, (where x = mg per Quercetin), $R^2 = 0.996$, where R is the coefficient of the regression line. The total flavonoid content of each extracts were calculated from the curve and expressed as milligram Quercetin equivalent per gram sample (mg QE/g) according to the formula by [20]

$$Total\,Flavonoid\,Content = \frac{(c\,x\,df\,x\,v)}{w}, \quad (3)$$

where c = concentration obtained from the standard curve, df = dilution factor, v = volume of stock solution, w = weight of dry cocoa beans extract used in the experiment.

2.8.2. Determination of Total Phenolic Content. The phenolic content was determined employing the Folin–Ciocalteu assay with gallic acid as a standard [17, 21–25] with slight modifications. Cocoa beans sample was ground and mixed thoroughly. 0.05 grams of the sample was weighed. Twenty (20) mL of ethanol were added and subjected to continuous agitation using the vortex. But the twenty (20) mL of ethanol was added in a series of 10 mL, 5 mL, and 5 mL to aid in high yield extraction. After the continuous agitation, the sample was left five (5) minutes to settle, and then, decanted. This procedure was repeated. Ethanol (40%) extracts was of phenolic content was determined employing the method involving Folin–Ciocalteu as oxidizing agent and gallic acid as standard method. Briefly, 3 mL of the deionized water was pipetted into the test tube, followed by the addition of 50 ul (0.5 mL) extract and 250 ul of the Folin–Ciocalteu reagent, and then, 750 μL of 20% sodium carbonate was added (w/v, 1.5 mL). Then, it was agitated to ensure mixing and incubation at room temperature for 30 minutes. Absorbance was determined spectrophotometrically at 760 nm by Shimadzu 1201, Japan. Distilled water was used as a blank or control. Gallic acid (25–500 μM) was used as a standard, and the results were

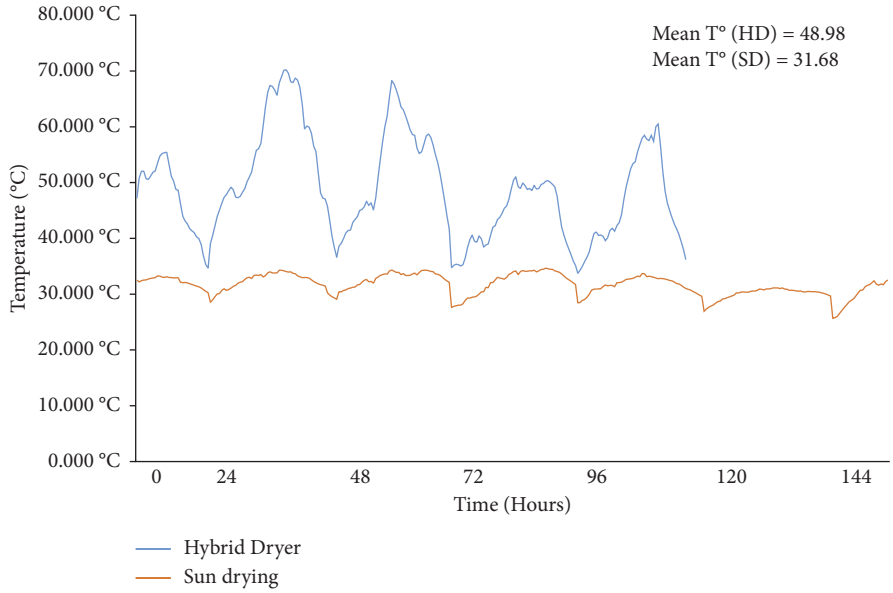

Figure 2: Temperature profile of the two drying methods during the drying period.

expressed as of mg gallic acid equivalents per gram of dried weight (mg GAE/g DW). Analyses were carried out twice. All determinations were performed in triplicate. Total phenolic content in each extract was determined from the respective curves and expressed as milligram. Gallic acid equivalent per gram sample (mg GAE/g) [26] using the following formula:

$$\text{Total Phenolic Content} = \frac{c\,x\,v}{m}, \quad (4)$$

where c = the concentration of Gallic acid established from the calibration curve in mg/g; v = the volume of dry cocoa beans extract in microlitres; m = the weight of dry cocoa beans extract in grams.

3. Statistical Analysis

Analysis of variance (ANOVA) was conducted using the statgraphics statistical software and the means were separated using the least significant difference (LSD) at 5% level ($p < 0.05$). All treatments and measurements were conducted in triplicates and the mean values reported.

4. Results

4.1. Temperature of the Two Drying Method during Drying the Period. The hybrid solar biomass dryer (HSBD) showed a gradual variation in temperature from day 1 with no changes until the end of day 5, when the drying period elapsed (Figure 2). The temperature ranged from 47.17°C to 35.28°C whilst the sun drying environment maintained almost a constant temperature of about 32°C throughout the drying period. There were significant differences ($p \leq 0.05$) between the hybrid solar biomass dryer and the sun drying over the drying periods with the hybrid solar biomass dryer recording significantly higher temperatures throughout the drying period (Figure 2).

4.2. Relative Humidity of Drying Environment during the Drying Period. The relative humidity of the drying environment over 5 days is shown in Figure 3. Higher relative humidity was recorded with respect to sun drying during the entire drying period than under the hybrid dryer. The highest relative humidity recorded for the hybrid dryer was 64.5% on day 5 of the drying period, while the highest relative humidity recorded was 83.4% on the fourth day of the drying period. The mean % RH of 32.5 and 65.8 was recorded for the hybrid dryer and sun drying, respectively. There were significant differences ($p \leq 0.05$) between the hybrid dryer and sun drying throughout the drying period.

4.3. Drying Period and Moisture Content Removal

4.3.1. Drying Period and Moisture Removal after Fermentation. Figure 4 shows the moisture removal rate of the two varieties under the two drying methods after 4 days of fermentation. The moisture loss of the solar biomass hybrid dryer was highest, with a reduction rate from 25.20% on the 1st day to 7.84% on the 3rd day. Hence, the solar biomass hybrid dryer achieved an efficient reduction of moisture. The beans were not subjected to drying on the 4th day because the desired moisture content of the seeds was achieved. Similarly, there was a steady decline in moisture loss from 28.50% on day one of drying to 6.84% on the 4th day in cocoa beans dried using the traditional sun drying method. There were significant differences ($p \leq 0.001$) in moisture loss for cocoa beans dried under the two drying methods.

In relation to the drying/moisture removal rate of the two varieties under the two drying methods after 5 days of fermentation as presented in Figure 4, the moisture loss rate declined from 45.83% on the 1st day to 7.17% on the 2nd day by the solar biomass hybrid dryer. Under the TSDM, the moisture reduction rate observed was from 33.80% on the 1st

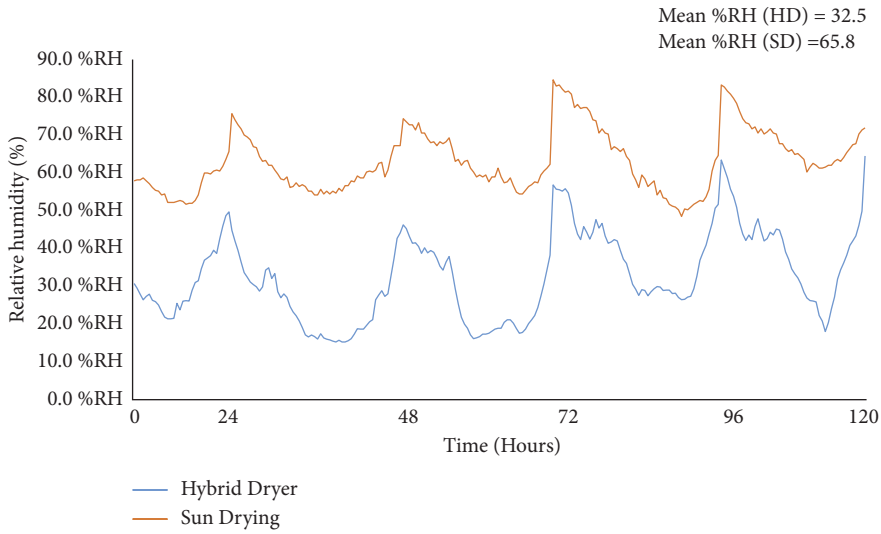

Figure 3: Relative humidity over the five–day period of drying.

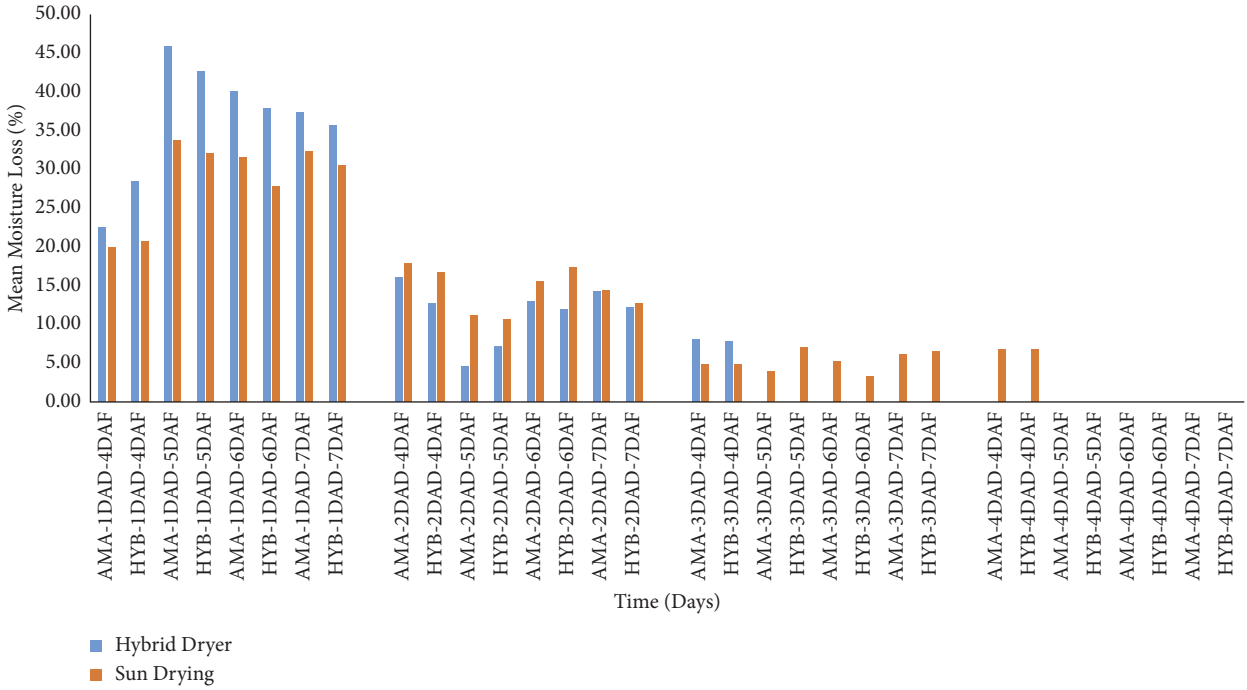

Figure 4: Mean moisture loss (%) of two cocoa varieties under different drying (4 days) and fermentation periods (7 days).

day to 7% on the 3rd day. Optimum moisture content was recorded on the 3rd day of drying. There was a significant difference ($p \leq 0.001$) in moisture loss for cocoa beans dried under the two drying methods.

In relation to the drying/moisture removal rate of the two varieties under the two drying methods after 6 days of fermentation, the moisture loss rate was from 40% on the 1st day to 12% on the 2nd day for cocoa beans dried under the SBHD, while the moisture loss under the TSDM was from 31.5% on the 1st day to 3.34% on the 3rd day in all the varieties.

The drying/moisture removal rate of the two varieties under the two drying methods after 7 days of fermentation, as shown in Figure 4, beans dried under the SBHD, moisture loss reduced from 37.33% on the 1st day to 12.17% on the 2nd day. With respect to the TSDM, moisture loss declined from 32.33% on the 1st day to 6.5% on the 3rd day. There was a significant difference ($p \leq 0.001$) in moisture loss for cocoa beans dried under the two drying methods.

5. Proximate Analysis and pH

The results of the pH and proximate analysis conducted on the cocoa beans used in the study are presented in Table 1 include the moisture content, free fatty acid content, fat content, *N*, and protein content.

Table 1: Proximate analysis and pH of cocoa varieties under different fermentation and drying periods.

Fermentation period (days)	Variety	Drying method	% Moisture content	% Free fatty acids	% Fat content	pH	% Nitrogen content	% Crude protein
4	*Amazonian*	Solar biomass hybrid dryer	6.90 ± 0.23^{ab}	41.67 ± 2.03^{abcd}	$\mathbf{38.83 \pm 1.96^{e}}$	$\mathbf{5.49 \pm 0.02^{a}}$	2.51 ± 0.07^{abc}	15.70 ± 0.46^{abc}
		Traditional sun dying	6.90 ± 0.23^{ab}	42.33 ± 1.76^{abcd}	29.83 ± 0.17^{bc}	5.56 ± 0.00^{abc}	$\mathbf{2.61 \pm 0.08^{c}}$	$\mathbf{16.28 \pm 0.51^{c}}$
	Hybrid	Solar biomass hybrid dryer	$\mathbf{6.80 \pm 0.17^{a}}$	39.00 ± 1.73^{abc}	23.17 ± 0.44^{a}	5.63 ± 0.00^{cde}	2.55 ± 0.03^{bc}	15.94 ± 0.18^{bc}
		Traditional sun dying	6.83 ± 0.15^{ab}	36.00 ± 1.15^{ab}	30.33 ± 1.33^{bcd}	5.52 ± 0.01^{ab}	2.51 ± 0.02^{abc}	15.70 ± 0.15^{abc}
5	*Amazonian*	Solar biomass hybrid dryer	6.93 ± 0.23^{ab}	48.00 ± 3.21^{abcd}	$\mathbf{23.00 \pm 1.26^{a}}$	5.58 ± 0.01^{abcd}	$\mathbf{2.26 \pm 0.22^{a}}$	$\mathbf{14.12 \pm 1.39^{a}}$
		Traditional sun dying	7.13 ± 0.09^{abc}	44.00 ± 2.08^{abcd}	31.50 ± 1.04^{bcd}	5.72 ± 0.01^{efg}	2.59 ± 0.16^{c}	16.17 ± 1.02^{c}
	Hybrid	Solar biomass hybrid dryer	7.30 ± 0.25^{bcd}	49.00 ± 3.79^{bcd}	27.83 ± 0.33^{abc}	5.66 ± 0.01^{def}	2.38 ± 0.09^{abc}	14.88 ± 0.53^{abc}
		Traditional sun dying	7.27 ± 0.15^{abcd}	$\mathbf{34.67 \pm 4.18^{a}}$	27.67 ± 0.88^{abc}	5.59 ± 0.01^{bcd}	2.53 ± 0.03^{abc}	15.82 ± 0.21^{abc}
6	*Amazonian*	Solar biomass hybrid dryer	7.47 ± 0.09^{cd}	41.67 ± 3.84^{abcd}	29.67 ± 1.86^{bc}	5.60 ± 0.02^{bcd}	2.46 ± 0.06^{abc}	15.35 ± 0.36^{abc}
		Traditional sun dying	$\mathbf{7.67 \pm 0.17^{d}}$	36.00 ± 3.46^{ab}	28.83 ± 0.88^{bc}	5.55 ± 0.01^{abc}	2.46 ± 0.02^{abc}	15.35 ± 0.15^{abc}
	Hybrid	Solar biomass hybrid dryer	7.43 ± 0.12^{cd}	$\mathbf{53.33 \pm 3.28^{d}}$	26.67 ± 2.42^{ab}	5.74 ± 0.01^{fg}	2.58 ± 0.07^{c}	16.11 ± 0.44^{c}
		Traditional sun dying	7.50 ± 0.12^{cd}	47.67 ± 3.93^{abcd}	32.33 ± 4.04^{cd}	5.65 ± 0.12^{def}	2.60 ± 0.10^{c}	16.22 ± 0.65^{c}
7	*Amazonian*	Solar biomass hybrid dryer	$\mathbf{7.67 \pm 0.17^{d}}$	49.67 ± 16.23^{bcd}	29.33 ± 2.19^{bc}	$\mathbf{5.78 \pm 0.01^{g}}$	$\mathbf{2.26 \pm 0.09^{a}}$	$\mathbf{14.12 \pm 0.57^{a}}$
		Traditional sun dying	7.43 ± 0.12^{cd}	45.00 ± 2.89^{abcd}	35.17 ± 2.17^{de}	5.51 ± 0.01^{ab}	2.28 ± 0.05^{ab}	14.24 ± 0.32^{ab}
	Hybrid	Solar biomass hybrid dryer	7.53 ± 0.03^{cd}	52.00 ± 1.53^{cd}	30.33 ± 1.48^{bcd}	5.58 ± 0.00^{abcd}	2.29 ± 0.07^{ab}	14.30 ± 0.41^{ab}
		Traditional sun dying	7.50 ± 0.12^{cd}	40.33 ± 3.28^{abcd}	30.00 ± 2.47^{bcd}	5.58 ± 0.01^{abcd}	$\mathbf{2.61 \pm 0.14^{c}}$	$\mathbf{16.28 \pm 0.86^{c}}$

"±SE = standard error, mean with same letters in a column are not statistically different ($p > 0.05$) from each other according to Fisher's least significant difference (LSD) procedure. Values bolded and underlined refers to samples with the highest concentration; bolded values represents samples with the lowest concentration."

5.1. pH. The pH of the cocoa bean samples ranged from 5.49 to 5.78. The highest pH was recorded in the Amazonian variety, dried under the SBHD, 7 days after fermentation, whilst the least pH was recorded in the Amazonian variety, dried under the SBHD, 4 days after fermentation. The significant differences ($p \leq 0.001$) existed in the fat content among the cocoa samples analysed.

5.2. Moisture Content. The moisture content ranged from 6.8%–7.6% with the highest value being recorded in the Amazonian variety, dried under the TSDM, after 6 days of fermentation, while the least was recorded in the hybrid variety, under the SBHD, 4 days after fermentation. There was a significant difference ($p \leq 0.001$) in the moisture content among the various cocoa bean samples.

5.3. Free Fatty Acids Content. The free fatty acid content (FFAC) ranged from 0.34% to 0.53%. The highest value was recorded in the hybrid variety dried under the SBHD, which was fermented for 6 days, while the hybrid variety, dried under the TSDM, fermented for 5 days, gave the least FFAC. There was no statistical difference in FFAC among the hybrid and Amazonian varieties, dried using the TSDM, at 4 and 6 days after fermentation, respectively. Highly significant differences ($p \leq 0.001$) existed in FFAC among the various cocoa bean samples.

5.4. Fat Content. The Amazonian variety, dried under the SBHD, 4 and 5 days after fermentation, had the highest and least fat content of 38.83% and 23.00%, respectively. There was statistically significant difference ($p \leq 0.001$) in fat content among the cocoa bean samples.

5.5. Nitrogen Content. The highest % *N* content of 2.61 was recorded in the Amazonian variety, under the TSDM, 4 days after fermentation, while the least % *N* of 2.26 was recorded in the Amazonian variety, under the SBHD, after 7 days of fermentation. This was not significantly different from the % *N* content of the hybrid variety, under the SBHD, 6 days after fermentation; the Amazonian variety, under the TSDM, after 5 days of fermentation; and the hybrid variety, under the TSDM, 6 and 7 days of fermentation. There were no significant differences ($p \leq 0.08$) in % *N* content among the cocoa beans analysed.

Table 2: Cut test properties of cocoa varieties under different fermentation and drying periods.

Fermentation period (days)	Variety	Drying method	Average bean count	Unusual beam count	Average tolerance level (ATL)	Germinated beans
4	*Amazonian*	Solar biomass hybrid dryer	104.67 ± 0.88^{ab}	27.67 ± 1.45^{ab}	0.09 ± 0.02^{a}	0.50 ± 0.12^{a}
		Traditional sun dying	107.33 ± 0.33^{bc}	29.00 ± 0.58^{abc}	0.09 ± 0.00^{a}	0.87 ± 0.30^{abc}
	Hybrid	Solar biomass hybrid dryer	**103.00 ± 0.58^{a}**	26.00 ± 0.58^{a}	**0.08 ± 0.00^{a}**	**1.00 ± 0.00^{c}**
		Traditional sun dying	104.33 ± 0.33^{a}	26.00 ± 1.15^{a}	**0.08 ± 0.00^{a}**	0.93 ± 0.07^{bc}
5	*Amazonian*	Solar biomass hybrid dryer	108.00 ± 0.58^{c}	29.33 ± 1.45^{abc}	0.09 ± 0.02^{a}	0.50 ± 0.06^{a}
		Traditional sun dying	113.33 ± 0.88^{d}	30.67 ± 1.86^{bc}	0.09 ± 0.02^{a}	0.73 ± 0.15^{abc}
	Hybrid	Solar biomass hybrid dryer	115.67 ± 0.67^{defg}	32.33 ± 0.67^{c}	0.09 ± 0.00^{a}	0.67 ± 0.20^{abc}
		Traditional sun dying	116.00 ± 1.00^{defg}	30.33 ± 1.45^{bc}	0.09 ± 0.00^{a}	0.57 ± 0.22^{bc}
6	*Amazonian*	Solar biomass hybrid dryer	115.00 ± 1.00^{de}	29.00 ± 1.53^{abc}	**0.08 ± 0.00^{a}**	0.50 ± 0.15^{a}
		Traditional sun dying	118.33 ± 0.88^{g}	30.67 ± 0.88^{bc}	0.09 ± 0.00^{a}	0.60 ± 0.15^{abc}
	Hybrid	Solar biomass hybrid dryer	115.33 ± 0.88^{def}	30.67 ± 1.20^{bc}	0.09 ± 0.00^{a}	0.50 ± 0.06^{a}
		Traditional sun dying	**118.00 ± 0.58^{fg}**	31.67 ± 0.33^{c}	**0.09 ± 0.00^{a}**	0.70 ± 0.12^{abc}
7	*Amazonian*	Solar biomass hybrid dryer	116.00 ± 1.00^{defg}	29.00 ± 1.53^{abc}	0.09 ± 0.00^{a}	0.60 ± 0.15^{abc}
		Traditional sun dying	117.33 ± 1.76^{efg}	30.67 ± 0.88^{bc}	0.09 ± 0.00^{a}	**0.50 ± 0.06^{a}**
	Hybrid	Solar biomass hybrid dryer	117.33 ± 1.76^{efg}	30.33 ± 0.88^{bc}	0.09 ± 0.00^{a}	0.63 ± 0.15^{abc}
		Traditional sun dying	115.33 ± 0.88^{def}	31.33 ± 1.20^{c}	0.09 ± 0.02^{a}	0.70 ± 0.12^{abc}

"±SE = standard error, mean with same letters in a column are not statistically different ($p > 0.05$) from each other according to Fisher's least significant difference (LSD) procedure. Values bolded and underlined refers to samples with the highest concentration; bolded values represents samples with the lowest concentration."

5.6. Crude Protein. The highest crude protein content of 16.21% was recorded in the Amazonian variety, under the TSDM, 4 days after fermentation, while the least % crude protein of 14.21% was identified in the Amazonian variety, under the SBHD, after 7 days of fermentation. This was not significantly different from the % *N* content of the hybrid variety, under the SBHD, after 6 days of fermentation; the Amazonian variety, under the TSDM, after 5 days of fermentation; and the hybrid variety, under the TSDM, after 6 and 7 days of fermentation. There was no significant difference ($p \leq 0.08$) in % *N* content among the cocoa beans analysed.

6. Polyphenolic Analyses

6.1. Total Phenolics Content. Variation in total phenolic contents (TPCs) of the ethanolic extracts of powdered cocoa samples as presented in Table2. The highest TPC was recorded by the hybrid cocoa variety that had undergone 5 days of fermentation and was dried using the solar biomass hybrid dryer (SBHD) (711.44 ± 63.77 mg GAE/g DW). This was not statistically different from the TPC of Amazonian under the same fermentation period and drying method. The Amazonian variety, fermented for 7 days and dried using the SBHD, had the least TPC of 305.11 ± 24.69 mg GAE/g DW. It was not statistically different from the values obtained by the hybrid variety, 5 and 7 days after fermentation and dried using the traditional sun drying method (TSDM) (362.69 ± 33.07 mg GAE/g DW) and SBHD (365.13 ± 16.28 mg GAE/g DW). Likewise, it was not statistically different from the TPC obtained by the Amazonian variety dried using the TSDM after 7 days of fermentation (365.13 ± 16.28 mg GAE/g DW). Concentrations of phenolics were highest in cocoa beans dried after 5 to 6 days of fermentation compared to those fermented for 4 or 7 days after fermentation. Mean TPC of the analysed samples was 443.897 mg GAE/g DW. Generally, there were significant differences ($p \leq 0.001$) between the varieties dried using different drying methods after different days of fermentation.

6.2. Total Flavonoid Content. The total flavonoid contents (TFCs) of the ethanolic extracts of dried cocoa bean samples, as presented in Table 3. The highest TFC of

Table 3: Total phenolics and flavonoids in cocoa varieties under different fermentation and drying periods.

Fermentation period (days)	Variety	Drying method	Phenolics (mg GAE/g DW)	Flavonoids (mg QE/g DW)
4	*Amazonian*	Solar biomass hybrid dryer	447.04 ± 5.32^{bc}	$1690.26 \pm 975.87^{abcd}$
		Traditional sun dying	450.28 ± 22.05^{c}	$2037.95 \pm 1176.61^{bcd}$
	Hybrid	Solar biomass hybrid dryer	433.25 ± 44.81^{bc}	**500.513 ± 288.97^{a}**
		Traditional sun dying	421.09 ± 34.82^{bc}	941.538 ± 543.60^{bcd}
5	*Amazonian*	Solar biomass hybrid dryer	618.98 ± 34.18^{d}	$2110.77 \pm 1218.65^{bcd}$
		Traditional sun dying	445.42 ± 37.96^{c}	2818.46 ± 1627.24^{d}
	Hybrid	Solar biomass hybrid dryer	**711.44 ± 63.77^{d}**	$1392.82 \pm 804.15^{abcd}$
		Traditional sun dying	362.69 ± 33.07^{abc}	$2213.33 \pm 1277.87^{bcd}$
6	*Amazonian*	Solar biomass hybrid dryer	447.04 ± 34.82^{c}	$2346.67 \pm 1354.85^{bcd}$
		Traditional sun dying	458.39 ± 59.00^{c}	$2438.97 \pm 1408.14^{bcd}$
	Hybrid	Solar biomass hybrid dryer	431.63 ± 53.80^{bc}	$1495.38 \pm 863.36^{abcd}$
		Traditional sun dying	460.83 ± 19.67^{c}	$1885.13 \pm 1088.38^{abcd}$
7	*Amazonian*	Solar biomass hybrid dryer	**305.11 ± 24.69^{a}**	1249.23 ± 721.24^{abc}
		Traditional sun dying	332.69 ± 4.06^{ab}	$1577.44 \pm 910.74^{abcd}$
	Hybrid	Solar biomass hybrid dryer	365.13 ± 16.28^{abc}	2736.41 ± 1579.87^{d}
		Traditional sun dying	411.35 ± 7.99^{bc}	**6069.74 ± 3504.37^{e}**
Mean			443.897	2094.04

"±SE = standard error, mean with same letters in a column are not statistically different ($p > 0.05$) from each other according to Fisher's least significant difference (LSD) procedure. Values bolded and underlined refers to samples with the highest concentration; bolded values represents samples with the lowest concentration."

6069.74 ± 3504.37 mg GAE/g DW was recorded in the hybrid variety dried using the TSDM after 7 days of fermentation, while the hybrid variety dried using the SBHD after 4 days of fermentation recorded the least TFC of 500.513 ± 288.97 mg GAE/g DW. In all the analysed samples, cocoa beans fermented and dried using the TSDM had higher TFCs than those dried using the SBHD. The mean TFC was 2094.04 mg GAE/g DW. There were significant differences among the analysed cocoa bean samples ($p \leq 0.0$ 01).

7. Physical Quality Analysis

7.1. Cut Properties of Cocoa Beans. Tables 2 and 4 shows the average bean count, unusual bean count, germinated beans, slaty beans, purple beans, germinated, and all other defective beans, as well as percent purity of the cocoa beans used for the study.

7.2. Average Bean Count. The average bean count ranged from 103.67 to 118.00. The highest average bean count was recorded in the Amazonian variety, dried under the TSDM, 6 days after fermentation. The least count was observed under the hybrid variety, dried under SBHD for 4 days after fermentation. There were highly significant differences ($p \leq 0.0001$) among the cocoa bean samples analysed.

7.3. Unusual Bean Count. The highest unusual bean count of 32.33% was found in the hybrid variety, dried under the SBHD, 5 days after fermentation, while the least unusual bean count of 26% was found in the hybrid variety, dried under the TSDM, 4 days after fermentation. There was a significant difference ($p \leq 0.016$) in the % unusual beans count among the cocoa samples studied.

7.4. Germinated Beans. There were a high percentage of germinated beans (100%) in the hybrid variety, dried under the SBHD, 4 days after fermentation. The least germinated beans of 50% was observed in the Amazonian variety, dried under TSDM, 7 days after fermentation; the Amazonian variety, dried under SBHD, 4, 5, and 6 days after fermentation; and the hybrid variety, dried under SBHD, 6 days after fermentation. There was no significant difference ($p \leq 0.32$) in germinated beans among all the cocoa bean samples.

7.5. Slaty Beans. There was no significant difference ($p \leq 0.12$) in percentage of slaty beans among the cocoa beans used for the study. The highest percentage of slaty beans (2%) was recorded in three samples (Amazonian variety, dried under TSDM, 5 days after fermentation; Amazonian variety, dried under SBHD, 5 days after fermentation; and hybrid variety, dried under SBHD, 4 days after fermentation). The least percentage of slaty beans (1.3%) was also recorded in the Amazonian variety, dried under the TSDM and SBHD, 6 and 7 days after fermentation, respectively.

7.6. Purple Beans. The highest purple bean count of 23 was recorded in the Amazonian variety, dried under the SBHD, 6 days after fermentation, while the least purple bean count of 22 was found in the hybrid variety, dried under the SBHD, 5 days after fermentation. There was no significant difference ($p \leq 0.97$) in purple bean count among the cocoa samples studied.

7.7. Germinated and All Other Defective Beans. The highest percentage of germinated and other defective beans recorded in (2.43) in the hybrid variety, dried under the TSDM, 4

Table 4: Cut test properties of cocoa bean varieties under different fermentation and drying periods.

Fermentation period (days)	Variety	Drying method	Purple beans	Total slaty beans	Germinated and all other defective	PTY %
4	*Amazonian*	Solar biomass hybrid dryer	22.57 ± 0.70^{a}	1.67 ± 0.20^{ab}	0.43 ± 0.13^{a}	97.77 ± 0.23^{ab}
		Traditional sun dying	22.57 ± 0.47^{a}	1.77 ± 0.29^{ab}	0.67 ± 0.32^{a}	97.47 ± 0.39^{ab}
	Hybrid	Solar biomass hybrid dryer	23.00 ± 0.85^{a}	$\mathbf{2.00 \pm 0.17^{b}}$	0.73 ± 0.22^{a}	97.43 ± 0.30^{a}
		Traditional sun dying	22.57 ± 0.59^{a}	1.80 ± 0.10^{ab}	$\mathbf{2.43 \pm 1.79^{b}}$	97.57 ± 0.37^{ab}
5	*Amazonian*	Solar biomass hybrid dryer	22.23 ± 0.29^{a}	$\mathbf{2.00 \pm 0.17^{b}}$	0.47 ± 0.12^{a}	97.67 ± 0.20^{ab}
		Traditional sun dying	22.77 ± 0.29^{a}	$\mathbf{2.00 \pm 0.40^{b}}$	0.77 ± 0.12^{a}	$\mathbf{97.37 \pm 0.33^{a}}$
	Hybrid	Solar biomass hybrid dryer	$\mathbf{21.90 \pm 0.20^{a}}$	1.67 ± 0.20^{ab}	0.90 ± 0.31^{a}	97.43 ± 0.13^{a}
		Traditional sun dying	22.90 ± 0.67^{a}	1.47 ± 0.23^{ab}	0.53 ± 0.23^{a}	97.77 ± 0.29^{ab}
6	*Amazonian*	Solar biomass hybrid dryer	$\mathbf{23.10 \pm 0.20^{a}}$	1.43 ± 0.30^{ab}	$\mathbf{0.30 \pm 0.00^{a}}$	$\mathbf{98.23 \pm 0.29^{b}}$
		Traditional sun dying	22.23 ± 0.47^{a}	1.33 ± 0.20^{a}	$\mathbf{0.30 \pm 0.00^{a}}$	98.10 ± 0.20^{ab}
	Hybrid	Solar biomass hybrid dryer	22.57 ± 0.70^{a}	$\mathbf{1.30 \pm 0.17^{a}}$	$\mathbf{0.30 \pm 0.00^{a}}$	97.67 ± 0.20^{ab}
		Traditional sun dying	22.57 ± 0.47^{a}	1.57 ± 0.13^{ab}	$\mathbf{0.30 \pm 0.00^{a}}$	$\mathbf{97.37 \pm 0.33^{a}}$
7	*Amazonian*	Solar biomass hybrid dryer	23.03 ± 0.33^{a}	1.33 ± 0.20^{a}	0.90 ± 0.31^{a}	$\mathbf{98.23 \pm 0.29^{b}}$
		Traditional sun dying	22.23 ± 0.47^{a}	$\mathbf{1.30 \pm 0.17^{a}}$	0.53 ± 0.23^{a}	98.10 ± 0.20^{ab}
	Hybrid	Solar biomass hybrid dryer	22.57 ± 0.70^{a}	1.57 ± 0.13^{ab}	$\mathbf{0.30 \pm 0.00^{a}}$	98.10 ± 0.20^{ab}
		Traditional sun dying	22.57 ± 0.47^{a}	1.33 ± 0.20^{a}	0.90 ± 0.31^{a}	97.67 ± 0.20^{ab}

"±SE = standard error, mean with same letters in a column are not statistically different ($p > 0.05$) from each other according to Fisher's least significant difference (LSD) procedure. Values bolded and underlined refers to samples with the highest concentration; bolded values represents samples with the lowest concentration."

days after fermentation, while the least (0.30) was recorded in the hybrid variety, dried under the SBHD and TSDM, 6 days after fermentation; Amazonian variety, dried under the SBHD and TSDM, 6 days after fermentation; and the hybrid variety, dried under the SBHD, 7 days after fermentation. There was no significant difference ($p \leq 0.34$) in the percentage of germinated and other defective beans among all the cocoa bean samples.

7.8. Purity. The highest bean purity of 98.23% was recorded in the Amazonian variety, dried under the SBHD, 6 and 7 days after fermentation, and the while the least 97.37% was recorded in the hybrid variety, dried under the TSDM, 6 days after fermentation, the Amazonian variety, dried under the TSDM, 4 and 5 days after fermentation. There were no significant differences ($p \leq 0.24$) in % purity among the cocoa samples studied.

8. Discussion

The traditional sun drying method has been used over the years by most farmers due to the no input cost and availability of sunshine. Though there are a number of negatives including slow drying rate and contamination by foreign materials, it is still the most preferred drying method by smallholder farmers. The reasons for its preference are manifold, it ensures proper drying of the beans as well as makes raking (stirring) of the beans easy. Drying is usually over in 5 or 6 days, depending on the sun. Over the past few years, researchers have made a number of interventions to introduce cocoa farmers to new drying methods and equipment to facilitate drying and enhance the quality of cocoa beans produced. Many of them have not been successfully adopted on a wide scale. It was in a similar direction that the solar biomass hybrid dryer was invented to facilitate the drying of cocoa beans in a hygienic environment at a faster rate.

In this study, the solar biomass hybrid dryer was very effective in ensuring the complete drying of the cocoa beans than the traditional drying method. It came to light that cocoa beans fermented for 5, 6, or 7 days dried earlier than those fermented for 4 days or less. The solar biomass hybrid dryer ensured effective drying after a drying period of 2 days.

The solar biomass hybrid dryer recorded higher temperatures than the traditional sun drying method. The effects of temperature and humidity on drying are interrelated. An increase in air temperature effectively lowers the relative humidity [27]. This was evidenced by the low relative humidity recorded in the solar biomass hybrid dryer, while the traditional sun drying method recorded higher relative humidity. Moisture absorbed by air was easily carried out of the drying environment since the solar dryer had a blower that blew hot air into the oven. Earlier, solar dryers did not have this feature [28]. In the initial stages of drying, when the surfaces of cocoa beans are saturated, the rate of moisture loss increases with increased air flow. The drying rate has been found to decrease with an increase in relative humidity [29]. Conversely, an increase in temperature at approximately constant humidity increases the drying rate.

Solar dryers are designed to trap absorbed heat, which gradually builds up in the drying compartment, resulting in higher temperatures. Whilst heat energy absorbed by sun drying is quickly lost because of the lack of an enclosure to keep the heat, hence a lower temperature was recorded as compared to the solar dryer. According to Thien and Yap [30], 80% relative humidity results in a small drying potential. Drying involves both heat and mass transfer. The solar biomass hybrid dryer was so efficient that within 2 days, the beans were thoroughly dried and the optimum/desired moisture content was achieved.

According to Zahouli et al. [31]; fermented cocoa beans generally contains between 55% and 60% moisture, and it must be reduced to less than 7.5% during drying to avoid spontaneous mould and bacterial growth during transport and storage [32]. The results obtained for the present study were within the range as differences were generally marginal. After fermentation, the moisture content was about 60%, and the moisture content after drying, which ranged from 6.8 %–7.6% was within the acceptable range and agrees with [32].

Free fatty acid (FFA) content is a signal of the degree of microbial impact by way of mould presence. It is the chemical trait that shows the degree of oxidation of the fat content of cocoa beans. Beans fermented under varying periods and dried with different drying methods showed significant differences in the free fatty acid content. The rancidity of cocoa is measured by the level of FFAs in the fat of cocoa beans. High FFA levels in cocoa are not acceptable (i.e. >1.75% in dried beans) [33]. Values obtained in this study were below the recommended FFA level. This could be as a result of the fermentation method and periods and as well as the drying method. Mould growth increases in foodstuffs when they are open to humid conditions (Raghavendra and Prakash [34]). For this reason, dark decayed beans as a result of exposed cocoa pods which have been infected by fungi could also create an environment for mould growth, which in turn increases FFA content in the beans [35].

The fat content of 38.83% and 23.00% was below the reported values of 56%–58%. Fat content or yield is a vital quality index used by cocoa processors during the purchase of fermented cocoa beans. Usually, cocoa beans have a fat content that ranges from 45–55%, but research revealed that the new varieties of cocoa have a much higher content than the 55% limit. The variations are as a result of the triacylglycerides content in cocoa beans which is accumulated in the beans based on the environmental condition like temperature that exist at where cocoa was grown.

pH plays an important role in determining the flavour of chocolate produced from cocoa beans. If the pH becomes too acidic too soon (pH < 4.5), there will be both a final reduction in flavour precursors and an over-acidic final product. The pH was found to be positively related to the acidity scores obtained from taste tests [36]. Rapid drying at a high temperature is known to lower the pH of dried beans [37]. Gorkeh–Sekyim [38] recommended that the pH of commercial beans should range between 5.0 and 7.0. Results from this study show that pH values obtained were within this range of 5.49 to 5.78, which is in consonance with Gorkeh–Sekyim [38]. The biochemical interactivity informs the pH of cocoa meant for the market and industry. Duration of fermentation is reported to affect the pH of beans by influencing enzyme activities and flavour development [39, 40].

Crude protein content ranged from about 14.21 to 16.21%. This is comparable to values from the literature, with values ranging from 15.2 to 19.8% [41, 42]. There was a general trend of a decrease in crude protein with fermentation for all the cocoa samples. Similarly, apparent decreases were observed as pod storage increased. The results, therefore, are an indication that protein content was significantly influenced by Nitrogen (*N*) content.

According to Lass and Wood [43], the void left in cocoa beans during germination can serve as a breeding ground for insects and fungal as well as encourage the growth of moulds. When there is a long delay in harvesting, pods get over ripe, giving rise to important stages of bean germination which deterioration and are of great concern [35, 41]. Insufficient drying is the primary cause of deterioration. Hence, in this study it was realized that those beans that were dried under both drying methods after 4 days of fermentation had higher percentage of germinated beans though below the critical allowable percentage of 3% according to international cocoa standards [2, 14].

According to the Ghanaian quality standards, slaty bean for grade one cocoa should not exceed 3% [14]. Values reported in this study (1.3–2%) were within the range. Unfermented beans have a slaty appearance; purple beans are poorly fermented, while increased browning and the reduction of purple coloration in the dried beans indicate an increased degree of fermentation, according to Lass and Wood [43]. A dark colour indicates that the bean has not been fermented. Slaty beans do not develop the characteristic chocolate aromas and brown colour.

According to Appiah [44], purple bean incidence has been of a major concern in Ghana over the past few years as it poses a great threat to the nations well known premium cocoa beans at the international level. The increasing change in brown beans with fermentation is suspected to be from changes occurring in anthocyanin and oxidation products of the polyphenol oxidase activities. This might have contributed to the brown pigments formed in the beans during the fermentation phase. The brown pigments could also be from complexation of condensed tannin, which is a high molecular weight product from flavonoid polymerization, with protein, via hydrogen bonding [45].

The process of ethanol oxidation into acetic acid as well as oxidation of polyphenol compounds leads to the purple beans reduction and the increase of percentages of brown beans [39]. During the aerobic phase of cocoa fermentation, the oxidation of polyphenols is largely responsible for the characteristic brown colour of fermented cocoa beans [46], the percentage purple beans decreases with ventilation. From the results obtained, purple colouration decreased drastically with the increasing duration of fermentation. This is so because purple colouration and loss of the characteristic chocolate brown colour are functions of fermentation. Lass and Wood [43] reported that purple bean is as a result of poor fermentation.

The results corroborate the report of Biehl et al. [39], who indicated that the high percentage of purple beans in cocoa fermented might be due to the short length of fermentation. Unfermented beans have a slaty appearance; purple beans are poorly fermented, while increased browning and the reduction of purple coloration in the dried beans indicate increased degree of fermentation, according to Lass and Wood [43]. According to Biehl et al. [39], indicators of well-fermented and well-dried quality beans are a good brown colour, low bitterness and astringency, and an absence of off-flavours such as smoky beans and excessive acidity. Adherence to the traditional fermentation period ensures much more decrease of anthocyanin or polyphenol (purple compound) content in cocoa beans to very low values (between 9 to 15%) whereas the three to four-day fermentation may keep the compound high (between 40 to 80%) in the bean where glycosides have not yet broken down [44].

The percentage purity of the cocoa beans under consideration was assessed in this work. This parameter is used in evaluating the overall effect of all the defects on the quality of the cocoa beans under study. The analysis revealed an overall good performance with the highest bean purity of 98.23% recorded in the Amazonian variety, dried under the SBHD, 6 and 7 days after fermentation. A high purity percentage was observed for all samples dried under the solar biomass hybrid dryer.

Total phenolic content (TPC) values recorded in this study are higher than those reported by Simao et al. [47], who reported TPC values of 16.46–56.21 mg/g/GAE in ethanolic extracts of leaves of some varieties. Low TPC values were recorded in the leaves of some accessions of cassava [48]. Similarly, low TPC values have been reported for some vegetables [49].

Studies have shown that environmental, climatic, or geographic factors may considerably impact quality and the quantity of phenolic components [50–52]. This can be attributed to the fact that ethanol is an organic solvent and was able to denature polyphenol oxidases as well as been more efficient in degrading cell wall, consequently being able to extract more endocellular materials than water [53]. Similar results were reported by [54], who stated that geographic factors in addition to extraction methods may considerably impact the quality and quantity of phenolic components of commodities [50–52].

Flavonoids are a group of more than 4000 polyphenolic compounds that occur naturally in foods of plant origin [55, 56]. Polyphenolic compounds have a common phenylbenzopyrone structure (C6-C3-C6) and are grouped based on their saturation level and the opening of the central pyran ring, mainly into flavones, flavanols, isoflavones, flavonols, flavanones, and flavanonols [55, 56]. Values reported in this study are higher than those reported by other workers [48, 57, 58], and Ahiapka et al. [59] in okra.

9. Conclusions

The study was carried out to determine the effects of different fermentation periods and different drying methods on the postharvest quality of beans of two cocoa varieties. From the results, a fermentation period of seven (7) days enhanced the development of the chocolate precursor for the flavour, appearance, and colour of the beans. Fermentation of cocoa beans for four (4) and five (5) days led to uncompleted chocolate flavour development as well as delayed the drying process.

Improper drying by the sun as a result of climatic change leading to unpredictable weather patterns could lead to beans insufficiently dried, which promotes the growth of fungi and mould, leading to poor quality.

The solar biomass hybrid dryer was more efficient in removing moisture from the beans as compared to sun drying method because it has an additional energy source which helps in maintaining low relative humidity within the drying chamber. The Amazonia variety of beans fermented for five (5) days under solar biomass hybrid dryer gave the highest moisture loss, pH, and the least fat content.

With reference to drying of fermented cocoa beans, the solar biomass hybrid dryer did better than the sun and on varietal differences; the Amazonian variety dried faster and gave the highest purity than the hybrid variety [60, 61].

Data Availability

Data are available upon request via odoom24@gmail.com.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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