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ORIGINAL ARTICLE

Chemical composition and physical quality characteristics of Ghanaian cocoa beans as affected by pulp pre-conditioning and fermentation

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Abstract Investigations were conducted to evaluate the effects of pod storage (as a means of pulp preconditioning) and fermentation on the chemical composition and physical characteristics of Ghanaian cocoa beans. A 4×2 full factorial design with factors as pod storage (0, 7, 14, 21 days) and cocoa treatment (fermented and unfermented) were conducted. Samples were analyzed for their chemical composition (moisture, crude fat, crude protein, ash and carbohydrate content) and mineral content using standard analytical methods. The physical qualities of the beans were analyzed for their proportions of cocoa nibs, shells and germ. Fermentation and increasing pod storage resulted in significant ($P<0.05$) decreases in ash (3.48–2.92%), protein (21.63–17.62%) and fat (55.21–50.40%) content of the beans while carbohydrate content increased from 15.47% to 24.93% with both treatments. As well, increasing pod storage and fermentation significantly ($P<0.05$) increased the copper content of the beans from while reductions in Mg and K occurred. Amongst the minerals studied, potassium was the most abundant mineral followed by magnesium, phosphorus and calcium in the fermented cocoa beans. Proportion of cocoa nibs also increased from with increasing pod storage and fermentation whiles reductions in shell content and no appreciable changes in germ proportions were noted.

Keywords *Theobroma cacao* · Pod storage · *Forastero* · Fermentation · Chemical composition · Physical quality

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Cocoa is one of the most important agricultural export commodities in the world and forms the backbone of the economies of some countries in West Africa, such as Cote d'Ivoire and Ghana. Cocoa beans are the fermented and dried seeds of *Theobroma cacao*, and the fundamental ingredient in chocolate manufacture. It is generally known to have originated from Central and Southern America. Currently, three broad cultivars of cocoa are commonly recognized: *Forastero*, *Criollo* and *Trinitario*. The cultivars exhibit differences in the appearance of pods, yields of beans, flavour characteristics and in resistance to pests and disease (Wood and Lass 1985; Asiedu 1989; Afoakwa et al. 2008; Afoakwa 2010; Adeyeye et al. 2010). Cocoa is largely produced in developing countries, but is mostly exported to and consumed in industrialized countries. Measured by volume of exports, the two main cocoa producing countries are Cote d'Ivoire and Ghana with an average annual production of ca. 40% and 20% respectively, making ca. 60% of global production. In 2008, West Africa alone accounted for ~71% of global cocoa supply (ICCO 2009).

In Ghana, cocoa has been labelled 'the golden pod' owing to the pivotal role it plays in the nation's economy. It is cultivated on about 1.5 million hectares of land by some 800,000 families in six out of the ten regions. It is cultivated almost exclusively by small-holder farmers with average farm sizes of about 4.0 ha and mean

production yields of 246.4 kg/ha (Afoakwa 2010; Knudsen and Fold 2011). The major cocoa type cultivated by farmers throughout Ghana is the *Forastero* variety with an average proportions cultivated cultivars being Amazonica (34.4%), the Amelonado (13.3%) and the hybrid (52.3%) (Afoakwa 2010).

Cocoa beans are mostly processed into chocolate and cocoa products using a wide range of intermediate products such as cocoa liquor, cocoa butter, cocoa cake and raw cocoa powder. Cocoa powder is essentially used in flavouring biscuits, ice cream and other dairy products, drinks and cakes and in the manufacture of coatings for confections and frozen desserts (Afoakwa et al. 2007; Pandey and Singh 2011; Frost et al. 2011; Rossini et al. 2011). It is also used in the beverage industry, for example in the preparation of chocolate milk. Cocoa butter is used in the manufacture of chocolate confectionery, soap and cosmetics (Ntiamoah and Afrane 2008; Schumacher et al. 2010). Other by-products such as cocoa pulp juice is also fermented to produce industrial alcohol and alcoholic beverages such as brandy and wine (Jayathilakan et al. 2011). Currently, the pod husks and shells are used for the preparation of animal feed and fertilizer in Ghana (Ntiamoah and Afrane 2008). The unique culture of producing high quality dried cocoa beans in Ghana, as engraved in the traditional farming practices of the peasant farmers, coupled with rigorous research and quality control programmes embarked upon consistently by successive Governments to date, has guaranteed Ghanaian cocoa its premium status on the international market.

Processing of cocoa beans into various cocoa and chocolate products starts with an on-farm fermentation of the beans followed by drying, and roasting during industrial processing. These postharvest processes are very crucial to the quality of finished products as they initiate the formation of chocolate flavour precursors and the brown colour of cocoa products (Schwan et al. 1995; Adeyeye et al. 2010). The fermentation process breaks down the mucilaginous pulp surrounding the beans and causes cotyledon death (Sanchez et al. 1985; Gotsch 1997; Afoakwa et al. 2008). This triggers biochemical transformation inside the beans, leading to reduction in bitterness and astringency, development of flavour precursors such as, free amino acids, peptides and sugars (Thompson et al. 2007; Kratzer et al. 2009; Rodriguez-Campos et al. 2011). Cocoa fermentation is influenced by many factors such as type of cocoa, disease, climatic and seasonal differences (Afoakwa 2010), turning, batch size (Lehrian and Patterson 1983), quantity of beans (Mamot and Samarakhody 1984; Wood and Lass 1985) and also pulp pre-conditioning (Meyer et al. 1989).

Pulp pre-conditioning entails changing the properties of the pulp prior to the development of microorganisms in fermentation. The pulp is the substrate metabolised during fermentation by a sequence of bacteria and fungi (Ostovar and Keeney 1973), and since the properties of the substrate determine microbial development and metabolism, changes in the pulp may affect the production of acids by lactic acid bacteria, yeasts and acetic acid bacteria. Three basic processes of pulp pre-conditioning have been evaluated for the treatment of fresh cocoa beans prior to fermentation – pod storage, mechanical or enzymatic depulping and bean spreading (Rohan 1963; Wood and Lass 1985; Biehl et al. 1989; Schwan and Wheals 2004).

Traditionally, Ghanaian farmers have unknowingly adopted this technique of pod storage by their practice of using family labour to collect the harvested pods into piles 3–5 days before organizing friends and neighbours to help break open the pods prior to fermentation (Duncan 1984). This method of pod storage appears to have highly beneficial effect on the chemical composition and subsequent development of chocolate flavour, though the precise chemical and biochemical effects, conditions and processes still remain unknown. With increasing specialty niche products in chocolate confectionery, understanding the factors contributing to variations in the chemical composition and physical qualities of cocoa beans during pod storage and subsequent fermentation processes would have significant commercial implications. Thus, this work investigated effects of pod storage (as a means of pulp pre-conditioning) and fermentation on the chemical composition and physical quality characteristics of Ghanaian cocoa beans.

Materials and methods

Materials

Ripe cocoa pods from mixed hybrids were harvested from the experimental plots of Cocoa Research Institute of Ghana (CRIG), Tafo in the Eastern Region of Ghana. The cocoa pods were selected according to their ripeness and maturity levels. The beans were pulp preconditioned by storing the harvested pods for a period of time before splitting. About 1,200 pods were stored (on the cocoa plantation) at ambient temperature (25–28 °C) and relative humidity of 85–100% for periods of 0, 7, 14 and 21 days respectively. The respective pods were then split after these predetermined storage times and fermented using the traditional heap method.

The fermentation was done by heaping about 50 kg of the extracted cocoa beans on the fermenting platform covered with banana leaves. The heaped beans were again covered with banana leaves and fermented for 6 days with consecutive openings and turnings after every 48 h.

Samples of the unfermented beans were picked into a sterile polythene bag under aerobic conditions and after the sixth days of fermentation, for drying and subsequent analysis. After each sampling time , the samples were immediately transported to the laboratory for drying by spreading the cocoa beans approximately 5 cm deep on metal trays (40 cm×60 cm), and placed in a temperature controlled, forced air oven for about 24 h at a temperature of 45–50 °C until dried (to moisture content below 8%). The dried beans were bagged in airtight black plastic bags and stored at ambient temperature (25–28 °C) in a dark room free from strong odours until used. Prior to chemical analyses, the dried samples were milled using a hammer mill (Model 2A, Christy and Norris Ltd., Chelmsford, England) and the resulting liquor packed in a black polyethylene bags and used.

Experimental design

A 4×2 full factorial design with experimental factors as pod storage (0, 7, 14, 21 days) and cocoa treatment (fermented and unfermented) were conducted. The samples were analyzed for their chemical composition moisture, crude fat, crude protein, ash and carbohydrate content (AOAC 2005). Mineral analyses were also determined using Atomic Absorption Spectrophotometer. The physical qualities of the beans were analyzed for their proportions of cocoa nibs, shells and germ.

Methods

Proximate analysis

The moisture, crude fat, crude protein and ash were determined following the procedures in AOAC (2005) methods 931.04, 963.15, 970.22 and 972.15 respectively. Carbohydrate was determined using 'by difference' method. All the analyses were performed in triplicate and the mean values reported.

Mineral analyses

Mineral analyses were determined using AOAC (2005) methods with slight modifications. About 0.5 g of the sample was weighed into a 250 ml beaker. Twenty five ml (25 ml) of concentrated nitric acid was added and the beaker covered with a watch glass. The sample was digested with great care on a hot plate in a fume chamber until the solution was pale yellow. The solution was cooled and 1 ml perchloric acid (70% $HCLO_4$) added. The digestion was continued until the solution was colourless or nearly so (the evaluation of dense white fumes was regarded to be indicative of the removal of nitric acid). When the digestion was completed, the solution was cooled slightly and 30 ml of distilled water added. The mixture was brought to boil for about 10 min and filtered hot into a 100 ml volumetric flask using a Whatman No. 4 filter paper. The solution was then made to the mark with distilled water.

Determination of Ca, Mg, Zn, Fe, Cu, Na and K

The concentrations of Ca, Mg, Zn, Fe, Na and K were determined using Spectra AA 220FS Spectrophotometer (Varian Co., Mulgrave, Australia) with an acetylene flame. One (1) ml aliquots of the digest was used to determine the Ca, Mg, Zn, Fe, Cu, Na and K content of the samples.

Phosphorus determination

Two (2) ml aliquot of the digest was reacted with 5.0 ml molybdic acid. The molybdic acid was prepared by dissolving 25 ml of ammonium molybdate in 300 ml distilled water; with 75 ml of concentrated sulphuric acid in125 ml of water to get 0.5 L of molybdic acid. One (1) ml each of 1% Hydroquinone and 20% Sodium sulphite was added in that sequence, and the solution was made up to 100 ml and allowed to stand for 30 min in order to develop colour after which the absorption was measured at 680 nm. A standard curve of colorimetric readings versus concentration of phosphorus using portions of standard phosphorus solutions (1 ml, 2 ml and 3 ml) subjected to reactions with molybdic acid, hydroquinone and sodium sulphate solutions were drawn. All readings were corrected using a blank to eliminate the effect of any colour produced by the reagents.

Physical quality analyses

Percentage nib, shell and germ

The percentage nib, shell and germ were determined according to the method described by Wood and Lass (1985). One hundred (100) grams of cocoa beans sample was weighed and the nibs carefully separated from the shells using a sharp knife and weighed separately. The germ were then carefully separated from the nibs and weighed. The percentage nib, shell and germ were calculated. The analyses were carried out eight times and the mean values reported.

Statistical analyses

The data were analysed using Statgraphics software version 3.0 (STSC Inc, Rockville, MD, USA) for analysis of variance (ANOVA). Least significant difference (LSD) was

used to separate and compare the means and significance was accepted at 5% level ($p<0.05$). All treatments were conducted in triplicates and the mean values reported.

Results and discussion

Chemical composition of pulp preconditioned fermented and unfermented dried cocoa beans

Proximate composition

Table 1 shows the proximate composition of unfermented and fermented cocoa beans under different pod storage periods. The moisture levels of the cocoa beans were considerably lower (3.89–4.95%) than the acceptable limits (6–7%) for long term storage of cocoa (Wood and Lass 1985; Dand 1997; Fowler 2009) hence the beans were quite brittle in nature. These relatively lower moisture content attained was to ensure that virtually all microbial and enzymatic reactions had ceased. Although the fermentation process reduced the water content of the beans there was still considerable amount of moisture lost during drying, thus confirming previous findings (Páramo et al. 2010). Fermentation introduced significant variation in the moisture levels (Table 2). Moisture levels were significantly lower ($p<0.05$) in all pulp preconditioned fermented cocoa beans than in the unfermented beans (Table 1) and this may be ascribed to the initial higher moisture levels of unfermented bean samples.

Crude protein content ranged from about 16 to 22% and this was comparable to literature values of 15.2–19.8% (Aremu et al. 1995; Afoakwa et al. 2008). There were general decreases in crude protein with fermentation for all the cocoa samples. Similarly, apparent decreases were observed as pod storage increased (Table 1). The results indicate that protein content was significantly influenced ($p<0.05$) by pod storage and fermentation time (Table 2). Further analysis using Least Significance Difference (LSD) revealed that the decreases amongst the 7 and 14 days pod storage were not significantly different. The protein content of the fermented cocoa beans reduced from 18.80 to 17.60% by 14 days of pod storage. The protein content was significantly reduced after 6 days of fermentation from 21.63 to 18.80% for the beans that were not stored (0 day pod storage) and likewise in all the beans that were pulp preconditioned (7, 14 and 21 days pod storage). These trends were consistent with reported literature by Biehl and Passern (1982), Biehl et al. (1985) and Crouzillat et al. (1999). Contrary to this, Aremu et al. (1995) reported a significant increase in bean protein content by the sixth day of fermentation. The observed decreases in protein content with pod storage and fermentation might be due to protein breakdown during the curing process, occurred partly due to hydrolysis to amino acids and peptides and partly by conversion to insoluble forms by the action of polyphenols as well as losses by diffusion (Afoakwa et al. 2008; Afoakwa and Paterson 2010).

Fat content or yield is an important quality index for cocoa processors during purchasing of fermented cocoa beans. In West African fermented and dried cocoa beans, the fat content ranges between 56 and 58% and most *Forastero* cocoas fall between 55 and 59% (Rohan 1963; Reineccius et al. 1972; Wood and Lass 1985; Afoakwa et al. 2008). The fat content of the beans as observed in this study were slightly lower than the reported values. Generally, the fat content ranged from 50.40 – 53.35% and 52.27 – 55.21% respectively for the pulp preconditioned fermented and unfermented beans. The fat content noted in the beans from the unstored pods were 53.35% and 55.21% for the fermented and unfermented

Table 1 Effect of pod storage (pulp pre-conditioning) and fermentation on proximate composition of cocoa beans

Pod storage (Days)	Fermentation condition	Moisture (%)	Protein (%)[a]	Fat (%)	Ash (%)	Carbohydrate (%)[b]
0	Unfermented	4.2 ±0.02	21.6 ±0.83	55.2±0.10	3.5 ±0.11	15.5 ±0.63
	Fermented	4.0 ±0.02	18.8 ±0.56	53.4 ±0.63	2.8 ±0.07	21.0 ±0.08
7	Unfermented	4.4 ±0.04	20.8 ±0.05	53.3 ±1.5	2.9 ±0.05	18.6 ±0.72
	Fermented	4.3 ±0.09	18.2 ±0.13	52.2 ±0.05	2.3 ±0.04	23.1 ±0.54
14	Unfermented	4.2 ±0.02	19.7 ±0.06	52.5 ±0.04	3.1 ±0.01	20.5 ±0.24
	Fermented	4.5 ±0.03	17.6 ±0.60	50.5 ±0.15	2.7 ±0.18	24.7 ±0.31
21	Unfermented	4.9 ±0.01	20.4 ±0.48	52.3 ±0.07	3.3 ±0.05	19.1 ±0.09
	Fermented	3.8 ±0.04	17.9 ±0.07	50.4 ±0.05	2.9 ±0.09	24.9 ±0.11

[a] Protein (N×6.25) [b] Carbohydrate was obtained using by difference method

Results presented are mean values of triplicate analysis±standard deviation

Table 2 ANOVA summary table showing F-ratios for variations in proximate composition of pulp pre-conditioned fermented and unfermented cocoa beans

Variables	Protein	Fat	Carbohydrate	Ash	Moisture
Pod storage (PS)	15.3*	166.5*	47.3*	28.4*	2.4
Fermentation time (FT)	16.1*	543.3*	397.7*	115.9*	16.9*
Interaction (PS x FT)	3.1	15.8*	3.3	3.1	23.8*

* Significant at $p<0.05$

beans respectively. Increasing pod storage, however, caused consistent reduction in the fat content of the cocoa beans such that after 21 days of pod storage, the fat content had decreased to 50.40% and 53.35% respectively for the fermented and unfermented samples. The observed variations in the fat content of the beans prior to pod storage and fermentation might be attributed to the relatively lower sizes of cocoa beans used in this study. Variations in the bean sizes could also account for the observed relatively lower fat content. Wood and Lass (1985) and Dand (1997) reported that smaller beans size results in lower fat yield.

Analysis of variance (ANOVA) on the data revealed that the fat content of the samples decreased significantly ($p<0.05$) with fermentation and pod storage (Tables 1 and 2) and this corroborate studies carried out by Aremu et al. (1995) in Nigeria where the lipid content of the cocoa beans decreased from 62.9% to 55.7% by the sixth day of fermentation. This suggests that the reductions in fat content in cocoa beans could be avoided by reducing fermentation time. Again, the consistent decreases in fat content noted with increasing pod storage might have resulted from the action of lipase enzymes which breakdown the triglyceride in the beans into its separate groups of fatty acids, thereby increasing the free fatty acids levels leading to the production of rancid flavour in the beans from the prolonged stored pods.

Carbohydrate content was significantly ($p<0.05$) higher in fermented samples than in unfermented samples (Table 2), with beans stored for 21 days prior to fermentation having the highest carbohydrate content. Pod storage influenced the carbohydrate content significantly ($p<0.05$) (Table 2). Further analysis by LSD showed that samples stored for 0, 7, 14 and 21 days were significantly different from each other. An apparent inverse relationship appears to exist between the levels of fat and total carbohydrate in fermenting cocoa. Conversion of lipid to carbohydrate via gluconeogenesis, employing the glyoxylate cycle could not be ruled out. It has been indicated that this pathway normally operates in microorganisms and germinating oil seeds (White et al. 1978).

The ash content of the cocoa beans decreased significantly ($p<0.05$) with fermentation and was generally comparable to literature values (Rohan 1963; Reineccius et al. 1972; Aremu et al. 1995). ANOVA indicated that the reductions in the ash contents due to fermentation and pulp preconditioning were significant ($p<0.05$), however pod storage of 7 days were significantly lower than the other pod storage days (Table 2).

Mineral content of pulp pre-conditioned fermented and unfermented cocoa beans

The effect of pulp preconditioning on the mineral composition of fermented and unfermented cocoa samples are shown in Table 3. Generally, there were decreases in the micronutrients with fermentation and increasing pod storage. The differences in mineral contents for all the different days of pod storage was significant ($p<0.05$). Also, differences among the unfermented and their corresponding

Table 3 Effect of pod storage and fermentation on mineral content of cocoa beans

Pod storage (days)	Fermentation condition	Mineral content (mg/100 g)							
		Fe	Cu	Mg	Zn	Na	Ca	P	K
0	Unfermented	2.7±0.04	11.1±0.03	286.8±3.19	9.7±0.06	3.4±0.01	140.2±0.60	236.6±23.08	2313.1±6.04
	Fermented	2.2±0.02	8.8±0.01	364.2±1.82	10.6±0.07	2.5±0.16	170.8±0.74	195.8±0.02	2557.9±11.01
7	Unfermented	2.5±0.02	11.5±0.13	318.6±7.27	9.3±0.06	2.5±0.04	141.1±0.60	264.4±184.62	2325.4±12.3
	Fermented	1.8±0.01	13.2±0.05	262.7±3.68	8.2±0.01	3.0±0.01	143.5±0.08	210.5±23.08	2164.2±10.26
14	Unfermented	2.2±0.02	13.7±0.02	331.5±6.89	9.3±0.05	3.3±0.08	158.2±0.38	292.1±23.08	2433.7±16.23
	Fermented	1.5±0.03	15.5±0.06	271.3±1.16	7.5±0.02	2.6±0.06	150.3±0.68	203.9±23.08	2095.6±6.98
21	Unfermented	1.4±0.01	15.3±0.12	349.2±2.98	9.4±0.25	2.7±0.04	142.8±0.07	381.9±46.16	2318.7±3.62
	Fermented	1.2±0.02	17.3±0.07	322.3±5.59	15.6±0.52	2.0±0.06	148.5±0.41	355.7±00	2070.7±5.71

Results presented are mean values of triplicate analysis±standard deviation

fermented samples were also significant ($p<0.05$). Iron generally decreased significantly ($p<0.05$) as pod storage days increased and with fermentation (Table 3 and 4). The iron content of unfermented cocoa samples that were not stored prior to fermentation was 2.73 mg/100 g and this decreased significantly by the end of the fermentation to 2.21 mg/100 g by the end of the fermentation (Table 3). Similar trends were observed in the beans stored for the other days of pod storage.

Copper content on the other hand increased as fermentation time and pod storage days increased. By 21 days of pod storage, the copper content of both the unfermented and fermented cocoa beans samples had increased respectively from 11.1 to 15.3 mg/100 g and 8.8 to 17.3 mg/100 g, suggesting approximately 100% increase in copper content in the fermented samples. This remarkable trend may be explained by the breakdown of anti-nutritional factors such as polyphenols and tannins during fermentation (Svanberg and Lorri 1997). Fermentation is known to provide optimum pH conditions for the enzymatic degradation of polyphenols which may be present in the cocoa beans in the form of complexes with polyvalent cations such as copper, zinc and proteins thus rendering them unavailable. Reduction in these anti-nutritional factors therefore might have increased the amount of soluble copper in several folds (Nout and Motarjemi 1997).

The magnesium content of the cocoa samples were significantly higher ($p<0.05$) in unfermented samples than in the fermented beans (Table 4). Pod storage, however had only marginal influence on cocoa beans with no precise trends in their observation.

Cocoa beans had low sodium content (2.04 to 3.35 mg/100 g) and were not significantly ($p>0.05$) influenced by fermentation although there were apparent differences observed amongst the samples (Tables 3 and 4). On the contrary, increasing pod storage caused general decreases in the sodium contents of the samples. ANOVA on the data showed that pod storage had a significant ($p<0.05$) influence on the sodium content of the cocoa beans (Table 4). Multiple comparison test showed that the beans stored for 0 and 14 days prior to fermentation were not significantly different from each other but the observed significant reductions were due to the differences in values from the 0, 7 and 21 days.

Generally, phosphorus content decreased with fermentation at all levels of pod storage (Table 3). Contrary to these, increasing pod storage (pulp preconditioning) caused consistent increases in the phosphorus content (Table 3). ANOVA on the data showed that both pod storage and fermentation had significant ($p<0.05$) influence on the phosphorus content (Table 4). Multiple comparison test (LSD) suggested that the phosphorus content at 0 and 21 days of pulp pre-conditioning were significantly different from each other and as well those from 7 and 14 days.

Cocoa beans had very high potassium content with values of 2557.92 and 2313.12 mg/100 g respectively for both the fermented and unfermented samples from the unstored pods (Table 3). Fermentation of the beans caused slight reduction in the samples to 2070.74 mg/100 g after 21 days of pod storage while the unfermented samples showed only marginal increases in K content with increasing pod storage. Analysis of variance on the data showed that the K content was significantly ($p<0.05$) by both fermentation and increasing pulp preconditioning (Table 4). These high values suggest that potassium is the most abundant mineral in Ghanaian cocoa beans and these might have originated from the soil on which the cocoa were planted.

Physical composition of pulp preconditioned fermented and unfermented cocoa beans

Proportion of cocoa nibs

The proportion of nibs ranged from 74.1 to 83.5% in the unfermented and fermented cocoa beans that were not stored prior to fermentation (Fig. 1a) and these values were slightly lower than those (86–90%) reported by Rohan (1963), Reineccius et al. (1972) and Afoakwa et al. (2008). These differences in nib content might have resulted from the harvesting season (whether major or minor) as these have been reported to affect the size of the beans (Rohan

Table 4 ANOVA summary table showing F-ratios for variation in mineral content of pulp pre-conditioned fermented and unfermented cocoa beans

Variables	Ca	Cu	Na	Mg	Fe	Zn	P	K
Pod storage (PS)	29.3*	4945.2*	51.1*	82.0*	1341.9*	322.8*	394.3*	1053.7*
Fermentation condition FC)	34.8*	2387.3*	0.1	577.3*	1365.6*	36.1*	84.5*	6180.3*
Interaction (PS x FC)	54.6*	13.8*	118.0*	20.8*	80.8*	322.8*	62.3*	118.5*

* Significant at $p<0.05$

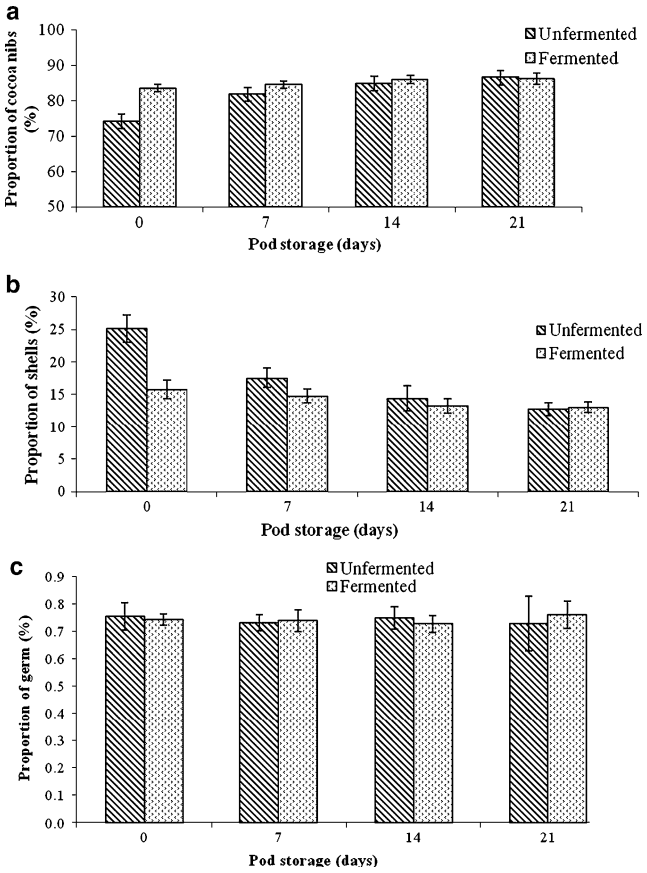

Fig. 1 Changes in proportion of cocoa nibs (**a**), shells (**b**)and germs (**c**) in pulp pre-conditioned fermented and unfermented cocoa beans

1963) and the important determining factors are suspected to be the amount and distribution of rainfall and temperature during the development of the pod (Rohan 1963; Wood and Lass 1985; Dand 1997). High temperatures and lower rainfall might have accounted for the smaller nib proportion of the cocoa beans used in the study. Generally, proportion of nib was slightly higher in the fermented cocoa samples than in the unfermented samples (Fig. 1a).

Pulp preconditioning and fermentation caused significant increases in weight of the cocoa nibs (Table 5). As illustrated in Fig. 1a, the nib recovery increased with increasing pod storage days as well as fermentation. The amount of pulp on the bean during shell separation would have much influence on the proportions. The amount of nib contained in the bean is of major concern to the cocoa processor since higher nib content results in higher nib recovery and fat yield. The apparent increase in weight of nib reflects a decrease in shell content.

Table 5 ANOVA summary table showing f ratios for variation in physical constituents of pulp pre-conditioned fermented and unfermented cocoa beans

Variables	Cotyledon	Shell	Germ
Pod storage (A)	295.7*	281.5*	0.7
Fermentation time (B)	275.7*	263.7*	0.1
Interaction (A x B)	118.6*	113.5*	0.6

* Significant at $p<0.05$

Proportion of shells

Even though the shell provides adequate protection to the nib from mould and insects infestations, the shell percentage should be as low as possible (10–14%). This is because the shell is removed during processing of the cocoa beans and has very little commercial value to the processor (Rohan 1963; Reineccius et al. 1972; Wood and Lass 1985; Dand 1997; Afoakwa et al. 2008). In the unfermented cocoa beans, shell content for all the pod storage ranged between 25.1 to 12.8%. By the end of the fermentation, the shell content had decreased significantly ($p<0.05$) for the different pod storage days. Figure 1b shows a sharp decrease from 25.1% to 15.8% shell content for 0 days pod storage. The considerably high shell content of all the unfermented samples could be ascribed to the adhering thick mucilaginous pulp immediately surrounding the testa prior to fermentation. Subsequent degradation of pectin by microbial pectinases during fermentation causes the liquefaction and drainage of about 10–50% of the pulp (Ouattara et al. 2008) and this might have accounted for the relatively lower shell content in the fermented cocoa beans.

Figure 1b also depicts a decrease in shell content as pod storage increased with beans stored for 21 days prior to fermentation having the lowest shell content (12.8%), and this could be attributed to the reduction in pulp volume by water evaporation occurring during pod storage (Biehl et al. 1989). This phenomenon could explain the decrease in shell content with increasing pod storage. Multiple range test (LSD) showed that the beans stored for the different pod storage days (0, 7, 14 and 21 days) were significantly different from each other. The cocoa bean shells make up waste material thus the lower the quantity, the more desirable it is to the cocoa processor.

Proportion of germ

The proportion of germ for the cocoa beans ranged from 0.73 to 0.75% for all the cocoa beans (Fig. 1c) and this is similar to results reported by Reineccius et al. (1972) (0.77%). Pulp preconditioning and fermentation time did not have any significant effect ($p>0.05$) on the proportion of germ of the cotyledons (Table 5). Pods stored for 21 days had their beans germinating and this accounted for the slightly higher proportion of germs and this observation may be attributed to pod rotting and the penetration of oxygen during pod storage (Meyer et al. 1989) hence providing favourable conditions for the germination of the beans.

Conclusion

Pod storage and fermentation influenced to varied levels the chemical composition and physical characteristics of Ghanaian cocoa beans. Chemical analysis on the samples revealed that fermentation and increasing pod storage resulted in consistent decreases in ash (minerals), protein and fat content of the beans while carbohydrate content increased with both treatments. As well, increasing pod storage and fermentation increased the copper content of the beans while reductions in Mg and K occurred. Amongst the minerals studied, potassium was the most abundant mineral followed by magnesium, phosphorus and calcium in both the fermented and unfermented cocoa beans. Proportion of cocoa nibs (fermentation yield) also increased with increasing pod storage and fermentation whiles these led to reductions in shell content were noted of the dried beans. However, no appreciable changes were noted with the proportion of germs with fermentation and increasing pod storage.

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