Post-harvest system and quality of cocoa beans in the southern region of Cameroon

Abstract

Aims: Multiple rejections of Cameroonian cocoa at the level of the international market proved that a commercial cocoa produced in this country still has an unstable quality. In view to contribute to the improvement of the quality of this product, investigations had been made on the post-harvest treatments. **Methodology**: An inquiry form on the techniques of post-harvest treatments had been effectuated in two cocoa production zones, notably Biwong Bulu and Mvangang subdivisions in the southern region of Cameroon. The fermented and dried beans were collected from farmers and their physicochemical characteristics were evaluated for their quality. **Results**: The results obtained show that the producers, made up on an average of 90% men, of which 38.3%, were elderly (> 50 years old) and were not affiliated to a cooperative, thus lacking knowledge of the quality criteria of commercial cocoa; as a consequence, the post-harvest cocoa processing method is not well respected. Only 41.8 % of the producers respected the order of the different unit operations of post-harvest treatment. There were four types of fermentation mode (box, banana leaves, tarpaulin and plastic bags) and three types of drying mode (hurdle, tarpaulin and soil). The different treatment modes significantly influenced the quality of the cocoa beans and thus, the morphological and physicochemical properties of the different samples. Large cocoa beans are obtained through fermentation in cascading crates (V = 1030 ± 50.90 mm3) and their drying on raised trays (V = 1310 ± 77.36 mm3), which is the material that allowed to quickly reach a moisture content conform (6.82 ± 0.91%) to cocoa of commercial quality.

Conclusion: The system of post-harvest treatment in the southern region of Cameroon was not respected as recommended. Sensitization and training farmers are necessary for the success of cocoa production in this region, particularly for these two subdivisions.

Keywords : Cocoa, fermentation mode, drying mode, physicochemical characteristics, quality

1. Introduction

The cocoa bean, properly fermented and dried, is highly prized for its aroma and nutritional value (50-57% butter, 10-15% protein, 8-12% fiber, 8% starch-type carbohydrates, about 5% minerals, vitamins and antioxidant molecules) [1]. On average, 4.728 to 5.024 million tons of cocoa are produced each year and its global trade is worth more than 76 billion euros ($105 billion) [2,3]. In Cameroon, the cocoa sector represents about 4% of the national Gross Domestic Product (GDP), 6% of primary GDP, and about 30% of the GDP of the agricultural products for export and processing subsectors. Cameroon's estimated production of 300,000 tons ranks 5th and is dominated by Forastero and Trinitario varieties [4,5]. Within the Cameroonian Forastero cocoa, different genetic groups stand out, including Amelonado, Contamana and Iquitos. Cameroonian cocoa, when processed under good conditions, produces beans of "*unique quality in the world*" and therefore highly prized and sought after on the international market [6]. With the liberalization in 1994, of the cocoa market in Cameroon, followed by the removal of the subsidy, the quantity and quality of production fell to a record figure of 150,000 tonnes in 2009 [7]. This decline resulted from the discouragement of producers whose crops were classified out of grades or rejected on the world markets because of its poor quality [8,9]. Despite the revaluation of the price of cocoa since 2012, the price of Cameroonian cocoa continues to decline despite the efforts of the peasant producers. In 2013 and 2015 European ports rejected, of part of Cameroonian production because of the moisture content largely above the norm (7-8%), the presence of slate and moldy beans and overall unpleasant tastes [7,10]. However, it is well known that obtaining a commercial cocoa product involves several steps of post-harvest processing, namely picking, pod incubation, podding, sorting, fermentation and drying, and eventually storage. All these operations affect the characteristics of the cocoa and the final product and are strongly interdependent. To understand the causes responsible for the poor quality of Cameroonian cocoa, the National Cocoa Academy of Cameroon has set up a program to characterize the production system and post-harvest treatments of cocoa in different growing areas. This initiative justifies the present work, which objective is to contribute to improvement the quality of Cameroonian cocoa through the characterization of the relationship between the post-harvest cocoa system and the quality of the product. The work was carried in the southern region of Cameroon, which produces brick-red cocoa, a colour highly prized by chocolate makers.

2. Methodology

2.1. Study area

This study was conducted in the subdivision of Biwong Bulu and Mvangang, which are the major cocoa-producing area in the southern Cameroon region. As it is shown on Figure 1, the villages surveyed were Doumba'a zok, Nkonmedjap II, Abiété, Ngomenden, Mbemang and Ababendoman.

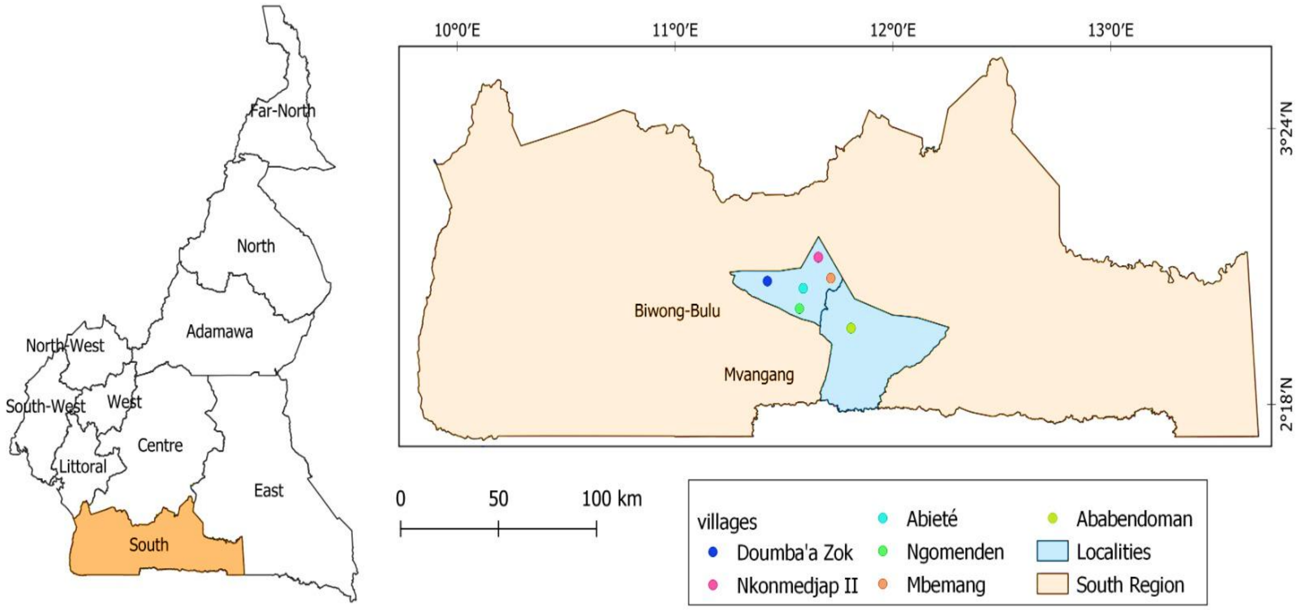

Figure 1: Location of study area

2.2. Methods

The study went through a survey of post-harvest practices, collection and analysis of cocoa samples at the different steps of the post-harvest process. Respondents were randomly selected among the producers of at least 3 years of experience in production and post-harvest processing of cocoa. Eighty cocoa producers' men and/or women were interviewed at the rate 40 per subdivision. The surveys took place in the plantations, at homes and in the cooperatives. The collection of information took place between September and November and via a questionnaire sheet which allowed to learn about the post-harvest treatment of cocoa in these areas. The aspects involved in the questionnaire concerned, the order of the different steps in post-harvesting treatment, materials used in harvesting and breaking, different fermentation modes, different drying modes, the storage mode, the duration of these operations and the knowledge of the different criteria of commercial cocoa by the farmers.

2.3. Sampling of cocoa beans

For the study of the influence of the fermentation mode on the morphological and physico-chemical characteristics, in each village and at randomly selected producers, 3 samples of 500 g of cocoa each were taken in each fermentation mode (in plastic bags, banana leaves and in a tarp) and one sample of the cocoa bean fermented in the cascading crates. All the samples were sun-dried on a tarp. Concerning the study of the influence of drying mode on these characteristics, the same quantities of samples fermented in banana leaves and dried at different drying modes were taken.

2.4. Analysis of cocoa beans

2.4.1. Morphological Analysis

Ten cocoa beans were selected randomly; their length (L), width (W), and thickness (T) were measured for three principal dimensions that were perpendicular in three dimensions by using a micrometer screw gauge at 0.01 mm accuracy as described by Baryeh [11]. The average diameter (Dg), sphericity (**φ**), geometric Surface area (S_a/mm^2) and the volume (V) of the beans were calculated by using the following relation as described by Tunde-Akintunde and Akintunde [13] ; Unal *et al*. [14]:

$$D_g = (L*W*T)^{1/3},$$

$$\varphi = D_g^2/L,$$

$$S_a = \pi . D_g^2$$

$$V = \frac{\pi}{6} D_g^3$$

2.4.2. Cut-test evaluation

The cut test is used for the evaluation of sanitary and fermentation quality of beans [15]. It was performed on the method described by Hamid & Lopez [16] and Hii *et al*. [17]. This technique was based on the color as a criterion for evaluation. It was used to appreciate the suitability of the beans for the manufacture of cocoa as described by Shamsuddin and Dimik [18]. Since the visual appreciation of the color of the cotyledons of the beans remains relative, because it varies from one operator to another, chromametric measurements according to CIE [19], were associated to quantify these different colors according to the parameters L*, C* and h [20]. The values obtained made it possible to identify the different colors in relationship to the level of fermentation. Indeed, the brown color will indicate that the beans are good fermented, the violet for those insufficiently fermented, the slaty color for the unfermented cocoa and the presence of white spots for molded beans. Regarding the cocoa classification, the criteria are recorded in Table 1 [21]. Data are expressed as percentages and analyses were performed in triplicate. The images of cocoa beans obtained by digital camera were analyzed using MATLAB programming to identify and calculate the values corresponding to each type of color.

Table 1: Classification criteria of commercial cocoa

Ranks	Brown (%)	Violet (%)	Molded (%)	Slaty (%)
I	≥ 80%	≤ 7%	≤ 3%	≤ 3%
II	≥ 75%	> 7%	≤ 4%	≤ 6%
Out of Grade (OG)	When the quality standards are higher than grade II			

2.4.3. Physico-chemical Analysis

The determination of moisture content was done by the AFNOR [22] method. The pH of filtrated mixure was measured using pHmeter by Hii *et al*. [23] and Tagro *et al*. [15] methods and a further 25 ml aliquot was titrated to an end point pH of 8.1 with 0.01N solution of NaOH. Titratable acidity was calculated using the formula proposed by Hamid & Lopez [16]. The total fat was extracted with a Soxhlet according to the method described by Bourely [24].

2.5 Statistical analysis

The survey sheets were examined, and the data collected were treated statistically using Sphinx 5.0 software (Le Sphinx Développement, Chavanod, France). An analysis of variance was also performed to compare the means of physicochemical and morphological parameters of the beans according to the fermentation and drying modes. In case of significant difference, Duncan's test was used to classify these means at thresholds between 1 and 5%.

3. Results and discussion

3.1. Cocoa producers: gender mapping and social status

Socio-economic characteristics of producers in the five villages involved in this study areas and their distribution according to age, gender and area under cocoa production are illustrated in Table 2. The majority of producers are men, with approximately 90%, which is comparable to the findings of Levai *et al.* [4] in the Fako Division in the Southwest region of Cameroon. The low involvement of women, or their absence in cocoa cultivation in some villages, is explained by the fact that according to custom, their access to land through purchase or inheritance is limited. This result is in line with the work of Lescuyer et *al.* [25], who showed that land tenure rules in Cameroon exclude women from access to the means of production from the outset and that gender equality is not recognized throughout the cocoa value chain, nor is it accepted in practice, although it is encouraged in discourse. In addition, women are not recognized in the sector other than as domestic labor on the same basis as children. In addition, the age groups of producers in this area show that they are made up of adolescents, adults and senior citizens.

Table 2. Distribution of producers according to age, sex and area of cocoa plantations

Villages	**Ages Interval (years)**	**Frequencies of age (%)**	**Frequencies by Sex (%)**		**Cultivated areas (hectars)**
			Males	**Female**	
Nkonmedjap II	20 - 50	55.6	88.9	11.1	1 - 10
	51 - 92	44.4			
Abiété	20 - 50	57.9	94.7	5.3	1 - 6
Yendjok	51 - 92	42.1			
Mbemang	20 - 50	50	100	0	1 - 4
	51 - 92	50			
Doumba'a zok	20 - 50	100	100	0	1 - 5
	51 - 92	0			
Ababendoman	20 - 50	40	100	0	4 - 18
	51 - 92	60			

Regarding socio-economic status (Table 3), the cocoa farmers are mostly married and are on average at the level of secondary education studies with the exception of producers in Mbemang village. In this village, 67% are at the level of the primary school. The cultivated cocoa areas are between 1 and 18 hectares and the data from the survey on production methods allow, according to the criteria of Ruf [26] and Lescuyer *et al.* [25] to classify cocoa cultivation in this area in four production systems, in particular small cocoa farms (0.5-5 ha) under shade and without external support; Small-scale cocoa farms under shade with external support; small-scale cocoa farms without shade and with external support; and medium-scale cocoa farms (5-20 ha).

Table 3: Distribution of producers by village and according to their matrimonial and education status

	Matrimonial and education status (%)						
Villages	**Married**	**Single**	**Divorced**	**Widow (er)**	**Primary**	**Secondary**	**University**

Nkonmedjap II	66.7	22.2	0	11.1	33.3	44.5	22.2
Abiété Yendjok	73.7	15.8	5.3	5.3	21.1	73.7	5.3
Mbemang	83.3	0	0	16.7	66.7	33.3	0
Doumba'a zok	80	20	0	0	40	60	0
Ababendoman	100	0	0	0	30	70	0
Ngomedeng	66.7	33.3	0	0	16.7	66.7	16.7

3.2. Post-harvest practices

The repartition of producers according to their ability to respect the order of the different unit operations of post-harvest treatments of cocoa beans as proposed by ICCO [27] is presented in Table 4. Only 42% of producers correctly follow the order of post-harvest processing operations, and that harvesting and podding are the two unitary operations carried out by all producers in the study area, while sorting, packaging and storage operations are carried out by only 40 to 50% of producers. Observations made in the field with producers show that even the procedures for conducting each of the unit operations of post-harvest treatments are not respected and some of the materials used are not suitable. Indeed, the harvest is normally done. However, the fact that its frequency depends mainly on the availability of labor would contribute to the presence of a large quantity of rotten pods in the batches intended for the incubation operation. Seventy-five percent of the producers in this area, take between one and two weeks, a period that greatly exceeds the incubation time of the pods, which is five days maximum according to ICCO [27]. This leads to the rotting and germination of the beans which are responsible for the unpleasant odors. As for podding, the machetes used to carry out this operation are a risk of quality alteration because its could injure the beans and cause contamination of the cotyledons. Stones could also increase the level of impurities in the commercial beans. However, the use of clubs and peeling machines by some producers meets the standards according to Barel [28]. Regarding the detachment of the placenta from the seeds, 97% of the producers do this operation manually or using a wire mesh fixed on a table. Sorting damaged or rotten beans, rachis and debris from cocoa hulls, however present in some batches, is the operation most neglected by 65% of producers. Nkonmedjap II remains the village where only 11% practice sorting of cocoa beans. This failure will lead to poor quality butter which will lower the market value of this cocoa [1,27]

Table 4: Distribution of producers according to their ability to respect the order of the different unit operations of post-harvest treatments

	Proportion of producers (%) in surveyed villages						
Order of Post-harvest units' operations	**Nkonmedjap II**	**Abiété yendjok**	**Mbemang**	**Doumba'a zok**	**Ababendoman**	**Ngomedeng**	**Mean (%)**
Harvesting	100	100	100	100	100	100	100
Incubation	55.6	78.9	50	100	80	83.3	74.6
Breaking	100	100	100	100	100	100	100
Removal of placenta	100	89.5	100	100	100	100	96.4
Sorting of beans	11.1	57.9	66.7	60	60	66.7	38.2
Fermentation	100	78.9	100	100	100	100	90.9
Drying	100	94.7	100	100	100	83.3	98.2
Conditioning	22.2	63.2	33.3	60	90	50	56.4
Storage	22.2	63.2	33.3	40	90	33.3	52.7

3. 2.1. Fermentation of fresh cocoa beans

In the areas studied, four types of equipment are used for fermentation (Figure 2), which reflects the existence of four modes of cocoa fermentation.

Figure 2: Fermentation in banana leaves (A), black tarpaulins (B), horizontal compartmentalized and cascaded crates (C and D)

The data on Figure 3 show that banana leaves constitute the material used in all localities by (78.2%) of producer's black tarpaulin is the least used (3.6%). Except in Nkonmedjap, for fermentation, 23.6% of producers use rectangular wooden crates with three compartments and the technique in cascade recommended by National Cocoa Academy. The net or plastic bag used by 14.6% of cocoa farmers in the Nkonmedjap II, Abiété and Ngomeden zones, are the prohibited materials even though they facilitate the flow of fermentation juice, its render the turning operation difficult. Leaves compare to other materials are the most used for the fermentation due to it easier accessibility. This result is in agreement with finding of Kouakou *et al*. [29]. Indeed, according to these authors, the cocoa tree is cultivated in association with bananas, as is the case in this study area, so that they benefit from their shade. However, tarpaulins and plastic bags require financial means to purchase or make them Kouakou *et al*. [29]. As for the cascades or horizontal crates, the high frequency of use is due to the fact that they are mostly offered to producers by the Ministry of Scientific Research and Innovation to encourage them to appropriate this fermentation technique which allow them to easily produce a grade I cocoa.

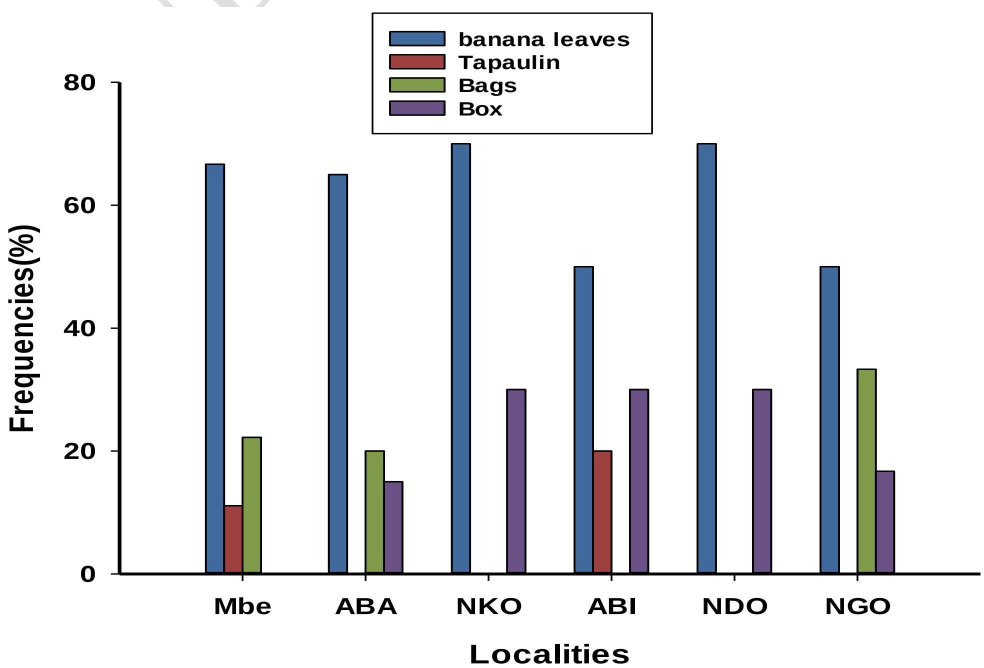

Figure 3**:** Frequency of use of fermentation equipment in the production area
NKO : Nkonmedjap II; ABI : Abiété yendjok ; MBE : Mbemang; NDO : Doumba'a zok; ABA : Ababendoman; NGO : Ngomedeng

The turning of cocoa beans, which is an essential operation for the success of fermentation, is practice by 40% of producers, and among the latter, and with regard to Figure 4, we note the presence of those who carry out late turning at the rate of once every three days in the localities of Mbémang (20%), Ngomedjap 2 (11%), Abiété Yendjock (10%) and Ndoumba'a zock (33%). The reasons given by those who do not turn their beans vary from one producer to another and include ignorance (18% of these producers), the tedious nature of turning in bags (11%) and the arduousness of this operation (12.5%) for large quantities of beans in fermentation.

These producers are classified into two groups: those who ferment cocoa beans in less than 5 days (60%) and those who do it less than 5 days (39.8%). Considering the criteria of Camu *et al*. [30] for a minimum period of 6 days of fermentation, the second group respects this recommendation. According to [1], the duration of the fermentation of cocoa beans in crates depends on the variety of the beans. Indeed, for Trinitario and Nacional cocoa, duration of 3 to 6 days is sufficient, 2 to 4 days are satisfactory for criollo while Forastero requires at least 5 days of bean fermentation. This second criterion raises the question of whether these producers adapt the duration of the fermentation of the beans according to the varieties produced, insofar as, in the field, they do not separate the beans according to the varieties.

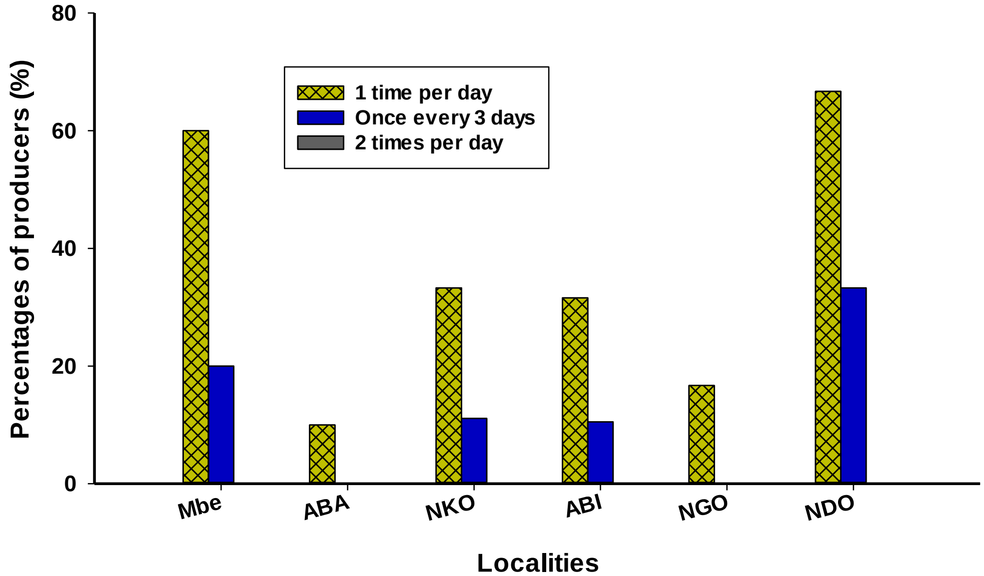

Figure 4: Frequency of turning of cocoa beans by producer
NKO : Nkonmedjap II; ABI : Abiété yendjok ; MBE : Mbemang; NDO : Doumba'a zok; ABA : Ababendoman; NGO : Ngomedeng

Regarding the duration of fermentation, between 87% and 96% of producers determine the duration of the fermentation of cocoa beans (Table 5).

Table 5: Distribution of producers (%) according to their ability to respect the order of the different unit operations of post-harvest treatments

Order of Post-harvest units' operations	**Different villages**						
	Nkonmedjap II	Abiété yendjok	Mbemang	Doumba'a zok	Ababendoman	Ngomedeng	Mean (%)
Harvesting	100	100	100	100	100	100	100

Incubation	55.6	78.9	50	100	80	83.3	74.6
Breaking	100	100	100	100	100	100	100
Removal of placenta	100	89.5	100	100	100	100	96.4
Sorting of beans	11.1	57.9	66.7	60	60	66.7	38.2
Fermentation	100	78.9	100	100	100	100	90.9
Drying	100	94.7	100	100	100	83.3	98.2
Conditioning	22.2	63.2	33.3	60	90	50	56.4
Storage	22.2	63.2	33.3	40	90	33.3	52.7

3. 2.2. Drying of fermented cocoa beans

The results of the survey show that at the end of the fermentation process, the cocoa beans are immediately spread out on the black tarpaulins, the racks placed on a high support or on the lightly cemented ground for their solar drying. These surfaces constitute the three drying materials (Figure 5) in this study area and their frequency of use varies from one locality to another.

Figure 5: Cocoa solar drying equipment: Hanging hurdle (A), Tarpaulin (B), On the soil(C)

Black plastic sheeting is used in all localities by 5 to 30% of cocoa farmers, while drying cocoa beans on the ground is practiced by 11 to 55% of producers in Mbemang, 55.6% at Nkonmedjap 2 and 22.2% at Abiété Yendjock (Figure 6). Regarding the rack, with the exception of Mbémang, this drying method recommended for obtaining good quality cocoa is much more practiced by the producers of Abiété (37%) and Ababendoman (41%). From the data obtained, producers in the surveyed areas of the southern region dry their fermented beans under the same conditions as in most producing countries. However, ground drying, which is strongly prohibited, continues to be practiced by some producers (20 to 25%). These results are in agreement with those of Kanmogne *et al.* [31] who indicate that in Cameroon 70% of cocoa farmers dry their beans on the ground by spreading them on a black tarpaulin, on a bamboo mat and on a cemented surface. Nevertheless, drying on an asphalt road was not identified in this area, as it was the case in 2012, showing that cocoa farmers are awared of the danger of poor quality of beans with this practice.

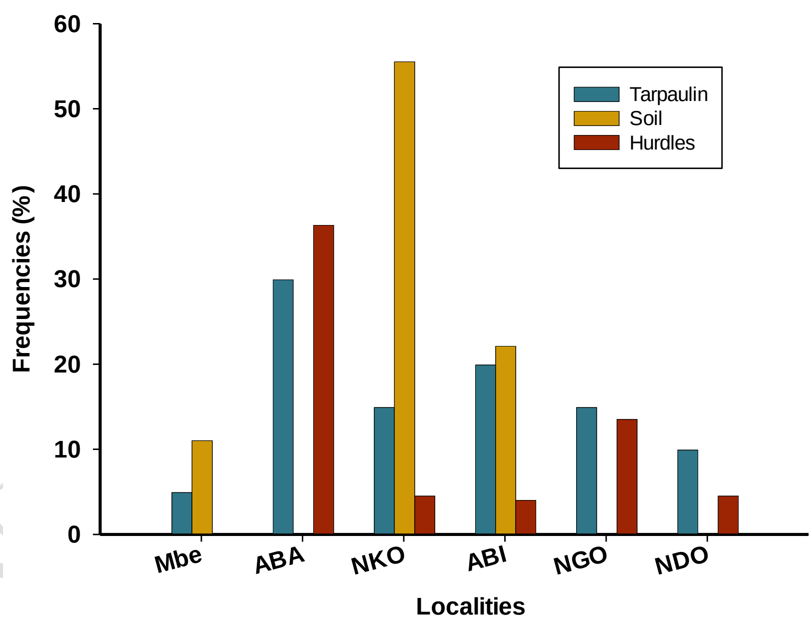

Figure 6**:** Frequencies of use of drying equipment in the study area

3.2.3. Packaging and storage of commercial cocoa beans

These are the last two post-harvest processing operations which are important insofar as a well fermented and dried cocoa will only keep its commercial quality when it is packaged properly, and the storage conditions are respected. The storage in the production area is a very delicate operation, because the slightest contamination by molds affects the final quality of the product. Indeed, cocoa beans must be packaged in appropriate packaging especially in jute bags and also stored in good conditions by avoiding heat and air humidity which promote the development of molds and insects [1,32]. Concerning the package of commercial cocoa beans, Figure 7 reveals that about 10 and 22% of the producers surveyed use jute bags (Figure 8, b) which are compliant. More than 80% of producers using plastic bags (Figure 8, a) recognize the poor quality of this type of packaging for cocoa, but they justify this choice by the irregular availability and high cost of jute bags.

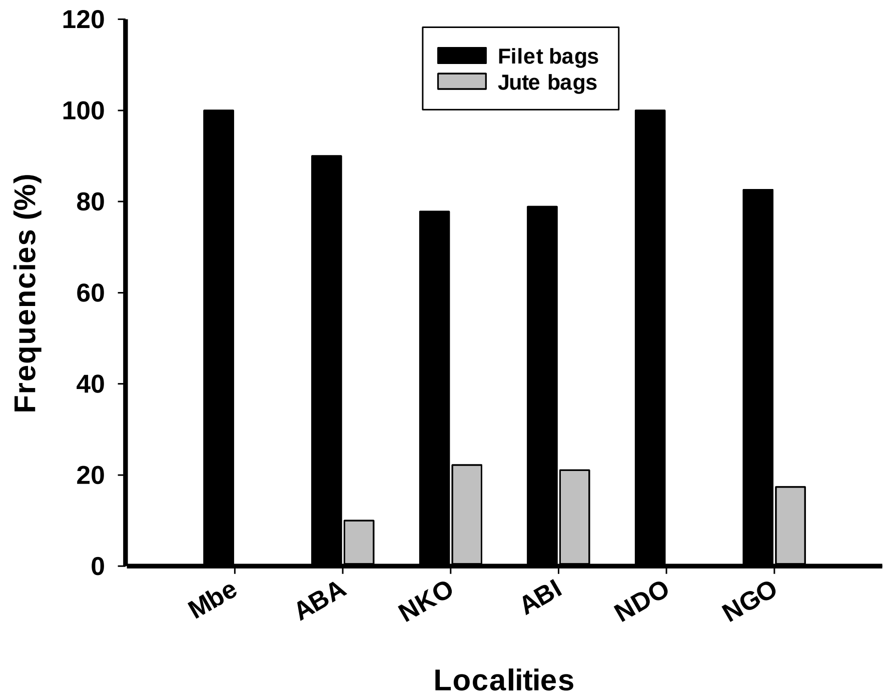

Figure 7: Frequencies of use of packaging materials of commercial beans

Figure 8: Conditioning and storage of cocoa beans using filet bags (A) and jute bags (B)

This situation will obviously lead to huge losses and this finding is in line with the work of Anang *et al*. [33], who showed that high post-harvest losses are among the major problems faced by cocoa-producing countries of the world, especially in developing countries with tropical environments. In addition, these authors have also shown that these losses are related to non-compliant packaging, a poor transport device and a poor storage system. This result is contrary to that of Oluchi *et al.* [34] who showed that about 90% of Nigerian cocoa farmers, especially those in Akwa Ibom State use jute packaging and storage warehouses with proper environment.

3.3. Influence of fermentation and drying modes on the morphological properties of cocoa beans

Morphological and physicochemical properties of cocoa beans according to the modes of fermentation and drying process were assessed and data are illustrated in Tables 6 and 7 respectively. It is known that the choice of post-harvest cocoa processing technologies is very important to obtain good quality beans and increase their market values. Indeed, the morphological properties of commodities determine the parameters necessary for the sizing and design of handling, transport, processing and storage equipment [11]. With regard to these tables, we can note that overall, the statistical analysis shows a significant influence at 5% of the different modes of fermentation and drying for all the morphological and physicochemical parameters of the analyzed beans. The volume of cocoa beans that depends on the geometric diameter and surface area is a parameter that gives an indication of the level of cocoa fermentation, because during this unit operation there is an increase in the volume of the cocoa bean [1]. The large volume cocoa beans (1030 ± 50.90 mm^3) are obtained with fermentation in cascading wooden crates followed by fermentation in banana leaves, while the smallest volume beans (737 ± 46.14 mm^3) come from fermentations in plastic bags (Table 6). In terms of drying, cocoa beans fermented in cascading crates and dried on racks are the most voluminous (1310 ± 77.36) than those indicated by drying beans spread out on the tarpaulin or directly on the soil. Subjected to the same source of heat which is the sun, this situation would be due to the evaporation associated with the speed of the air, and also to the surface of contact of the air with the cocoa beans in drying. Indeed, cocoa beans spread on high racks (compared to those on tarpaulins or on the soil) receive much air ventilation on all the contact surfaces, which leads to rapid dehydration, this limit conduct to the biochemical reactions that would be one of the factors responsible for the decrease in volume of the beans during drying. Regardless of the method of fermentation and drying used, the sphericity of cocoa beans did not differ significantly. This result is contrary to those of Mohammad *et al*. [35] who showed a proportional increase in the length of cocoa beans with thickness.

3.4. Influence of fermentation and drying modes on the physicochemical properties of cocoa beans

The physico-chemical characteristics of the analyzed beans were significantly (**: $P < 0.01$; ***: $P < 0.001$) influenced by the different fermentation ($F = 4.72 - 8.84$) and drying (4.19 – 21.16) methods used by the producers. Regarding the influence of the type of fermentation, the results obtained are those of the beans dried on the tarpaulin and spread on the ground, which constitutes the material used by the majority of the producers while for the study of the mode of drying, it was carried out on the beans fermented on the most used material which is the banana leaf.

The moisture and lipid (cocoa butter) contents vary between 7.20 and 13.10% and between 32.55 and 48.21% DM respectively. The lipid contents of cocoa beans fermented in cascading crates box (48.21% DM) and that of cocoa beans fermented in banana leaves (45.24% DM) comply with the standard recommended by the FAO, which is between 45 and 55% [21], while they are low for beans packed in tarpaulin and in bags. For these beans subjected to the different fermentation modes, it is normal that after drying under the same conditions, the cocoa fermented in inadequate devices (tarpaulin and plastic bags) have high water content due to the bad fermentation. Indeed, according to Apriyanto *et al.* [36], during the fermentation process, there is a decrease in water content that occurs through diffusion and evaporation of water from the inside to the outside of the bean. For Ban *et al.* [37], different fermentation modes and techniques influence the microbial flora differently and lead to a change or variability in the physicochemical composition of fermented beans. In addition, the fact that the turning of the beans and the draining of the fermentation juices are two important unitary operations that are difficult to carry out in these types of fermentation would have a negative impact on the level and quality of fermentation achieved by the producers. The titratable acidity of cocoa beans characterized by acidic pH values results from the fact that during fermentation, the microbial flora uses the pulp as a substrate (glucose, fructose, sucrose) to produce organic acids. From Table 6, the pH and titratable acidity of cocoa fermented in tarpaulins (5.21 and 2.33 meq of $NaOH.g^{-1}$ of dried cocoa bean) and plastic bags (5.04 and 2.58 meq of NaOH. g-1 of dried cocoa bean) are more acidic than those fermented in crates (6.42 and 1.12 meq of NaOH.g^{-1} of dried cocoa bean) and in banana leaves (6.27 and 1.28 meq of NaOH.g^{-1} of dried cocoa bean). These results are in agreement with those obtained by Tagro *et al.* [15], who showed that fermentation in plastic bags produces highly acidic cocoa. Indeed, although acetic and lactic acids are produced during fermentation in crates and in banana leaves, the aeration of the medium through proper stirring of the beans every 48 hours in these materials would have led rather to an acetic fermentation than to a lactic fermentation in the medium. These acids migrate from the outside to the inside of the beans. Then, according to Thompson *et al.* [38], the solar drying applied to dry these beans causes the evaporation of acetic acid. On the other hand, according to Tagro *et al*. [15], the high acidity of fermented beans in plastic bags and tarpaulins could be explained by a probable high lactic acid fermentation due to insufficient liquid drainage and poor aeration of the beans which provokes the growth of lactic acid bacteria and inhibits acetic acid bacteria, in spite of two stirring operations carried out by the producers after 48 and 96 hours of fermentation. However, since lactic acid is not volatile, it will remain in the cocoa bean [39] and lead to an increase in the amount of acid, characterized by low pH values compared to those obtained with fermentations in crates and in banana leaves.

During the drying of the beans, there is a loss of water and acidity (acetic acid) and this level of loss, which depends on the drying time, would also be a function of the type of material used. Table 7 shows that the lowest moisture content (6.82%) and titratable acidity (0.94 meq of NaOH.g^{-1} of dried cocoa bean) are obtained with drying on hurdle. This indicates that this material would be the most recommended for producers in this region of the country. This result is in contrary with to those of Akmel *et al.* [40] who showed no significant difference in the effects of these devices on acidity and moisture of dried beans. The type of drying material has a significant influence ($P<0.01$; $F= 21.16$) on the lipid contents of dried beans. Compared to the lipid contents of dried beans (48.37%MS) on hurdle, lower values are observed for beans dried in tarpaulins (44.4%MS) and on the soil (46.03%). This observation could be explained according to Potillon [41] by the fact that the solar or natural drying being long (7 to 21 days), the dehydration is slow, because it strongly depends on the climatic conditions or the seasonal variability. During this drying, the biochemical reactions started during the fermentation continue and with these periods of interruptions of drying, there is a recovery of moisture by the cocoa beans, which leads to additional hydrolysis reactions of lipid that are illustrated by their decreases in the beans dried in the tarpaulin and on the soil. The good quality of cocoa dried on racks could be explained by the fact that during drying, the air from the ventilation is in contact with the entire surface of the beans because of the porosity of the racks. As a result, this material is then favorable to a good evaporation of acetic acid and allows the reduction of biochemical reactions of lipid hydrolysis. The impurities in cocoa beans, consisting of stones and plant debris, is significantly influenced at the 1% threshold ($F=6.52$) by the drying equipment used. The highest levels of impurities were found in the cocoa beans dried on the ground, especially those spread out on the cemented surface (35.84 ± 8.76 %) and on the black tarpaulin (14.26 ± 4.41 %), while the lowest level of impurity was found in the cocoa beans dried on the drying rack (4.41 ± 2.1 %). According to Kouakou *et al*. [29], this result is explained by the fact that unlike cocoa beans dried on hurdle, which are generally elevated, those spread out on tarpaulins and cemented areas installed on the ground are constantly in contact with foreign bodies such as grains of stones, parts of plant organs and animal detritus.

Table 6: Morphological and physico-chemical properties of cocoa beans dried on tapaulin by fermentation mode

Fermentation modes	**Morphological properties**				**Physico-chemical properties (g/100g DM)**			
	Dg (mm)	**Sp**	**V (mm^3)**	**Sa (mm^2)**	**Moisture content**	**Lipid content**	**pH**	**TA**
Box	12.38 ± 0.40^{a}	0.52 ± 0.01^{a}	1310.00 ±50.90^{a}	362.00 ± 22.66^{a}	6.20 ± 0.81^{b}	48.21 ± 0.24^{a}	6.27 ± 0.12^{b}	1.12 ± 0.04^{a}
Banana Leaves	10.72 ± 0.23^{b}	0.52 ± 0.01^{a}	886.00 ± 80.22^{b}	352.00 ± 13.31^{b}	7.29 ± 0.79^{b}	45.24 ± 2.15^{b}	6.42± 0.00^{a}	1.28 ± 0.05^{b}
Tarpaulin	11.51 ± 0.43^{ab}	0.50 ± 0.01^{a}	861.00 ± 77.72^{b}	351.00 ± 22.30^{b}	13.10 ± 0.47^{a}	40.40 ± 0.74^{c}	5.21 ± 0.04^{a}	2.33 ± 0.16^{b}
Bag	11.21 ± 0.20^{ab}	0.50 ± 0.01^{a}	737.00 ± 46.14^{c}	340.00 ± 12.60^{c}	12.98 ± 1.59^{a}	32.55 ± 0.45d	5.14 ± 0.03^{a}	2.58 ± 0.04^{b}
F-value	3.37*	1.37^{ns}	3.44**	3.81*	4.72***	6.14***	8.14**	8.84***

*ns: not significant; *: P < 0.05; Means within the same column followed by the same letter' (s) are not statistically different at 5 % level (Tukey test); Dg: geometric diameter, Sp: sphericity; V: volume; Sa: surface area; TA: Titratable Acidity*

Table 7**:** Morphological and physico-chemical properties of cocoa beans fermented on bananas leaves by drying mode

Fermentation modes	**Morphological properties**					**Physico-chemical properties (g/100g DM)**			
	Dg (mm)	**Sp**	**V (mm^3)**	**Sa (mm^2)**	**Impurities (%)**	**Moisture**	**Lipid**	**pH**	**TA**
Soil	11.04 ± 0.81^{b}	0.51 ± 0.03^{a}	854.00 ± 118.00^{b}	343.00 ± 37.76^{b}	35.84 ± 8.76^{a}	10.15 ±0.30^{a}	46.03 ± 1.09^{c}	5.25 ± 0.01^{a}	1.64 ± 0.10^{c}
Tarpaulin	11.51 ± 0.43^{ab}	0.50 ± 0.02^{a}	886.00 ± 80.23^{b}	362.00 ± 22.66^{b}	14.26 ± 4.41^{b}	9.10 ± 0.82^{a}	44.40 ± 0.73^{b}	6.42 ± 0.04^{b}	1.28 ± 0.16^{b}
Hurdle	13.13 ± 0.27^{a}	0.54 ± 0.01^{a}	1030.00 ± 77.36^{a}	462.00 ± 18.05^{a}	4.4 ± 2.1^{c}	6.82 ± 0.91^{b}	48.37 ± 0.22^{a}	6.51 ±0.10^{b}	0.88 ± 0.02^{a}
F-value	3.93*	0.67^{ns}	7.38**	5.42*	6.52**	**8.29*****	**21.16****	**9.26*****	**4.19*****

*ns: not significant; *: P < 0.05; **: P < 0.01; ***: P < 0.001; Means within the same column followed by the same letter' (s) are not statistically different at 5 % level (Tukey test); Dg: geometric diameter, Sp: sphericity; V: volume; Sa: surface area; TA: Titratable Acidity*

3.5. Classification and grades of fermented and sun-dried cocoa beans

The grades of fermented and sun-dried cocoa beans were evaluated as described by Ban *et al*. [37] and results are illustrated in Table 8. In addition, the different colors observed and identified by the cut test were quantified according to the chromametric method of CIE, 1978. This table shows the color of the cocoa beans according to the fermentation method used in the different villages. The determination of the color of the cotyledons of commercial beans is a very important criterion used to identify their fermentation and moisture levels, which are elements that allow these products to be classified by grade [1]. Indeed, cocoa is a grade I, if and only if the percentage of moldy, defective and slate beans is less than 3% for each. It is grade II if their values are less than 4, 8 and 6% respectively for moldy, defective and slate beans. Beyond these values, the cocoa is considered out of grade. With regard to this table, and for each fermentation method, there is a variability in the proportions of brown beans and purple beans which is between 26.6 and 93.2% and between 6.8 and 50% respectively and characterized by batches of grades I, II and out of grades. The fermentations in tarpaulins and plastic bags produced about 75% of poor-quality commercial beans in all localities, with the exception of beans collected in Abiété Yendjock and Ababendoman villages, which were of grade II. According to Tagro *et al*. [15], this poor quality of cocoa beans obtained with this fermentation method is the result of the plastic nature of these two materials, which would reduce microbial growth, contrary to the crates and banana leaves, whose biological nature is conducive to the development of these microorganisms. In addition, for each of the fermentation methods used, there is variability in the quality of cocoa beans depending on the localities.

Indeed, these results are in agreement with those of Hii *et al* [17] who showed that the quality of a commercial cocoa also depends on several factors including the variety used, environmental conditions (microbiota, temperature and relative humidity) and the cultivation and post-harvest practices used in cocoa production areas. However, fermentation in cascading wooden boxes proposed by researchers at the National Cocoa Academy (NCA) allows for improving cocoa quality compared to others fermentation equipment's.

Table 8: Classification of cocoa beans with respect to its colour attributes

Fermentation mode	Cocoa bean production areas	**Nature and colors of cocoa beans**				**Ranks**
		Brown (%) L= 15 - 90 H= 35- 75 C= 5-10	**Violet (%) L= 0 - 90 H=-15–(-60) C= 10 -12**	**Molded (%) L= 0 - 30 H= 0 - 30 C= 5-10**	**Slated (%) L= 90 - 100 H= -60 - 90 C= 8 -12**	
Boxes	Nkonmedjap II	46.6	50	3.4	0	II
	Abiété Yendjok	43.3	46.6	3.4	6.7	II
	Mbemang	90	10	0	0	I
	Doumba'a zok	46.8	46.6	3.3	3.3	II
	Ababendoman	83.3	16.8	0	0	I
	Ngomedeng	93.2	6.8	0	0	I
Banana Leaves	Nkonmedjap II	43.3	36.6	13.3	6.7	OG
	Abiété Yendjok	40	50	3.3	6.7	II
	Mbemang	79.9	16.7	3.3	0	II
	Doumba'a zok	50	40	6.7	0	II
	Ababendoman	66.6	26.6	3.3	0	II
	Ngomedeng	76.6	20.1	3.3	0	II
Tarpaulins	Nkonmedjap II	40.5	33.3	13.3	10.4	OG
	Abiété Yendjok	66.6	26.6	3.4	0	II
	Mbemang	53.3	30	16.7	0	OG
	Doumba'a zok	36.6	33.3	23.3	6.7	OG
	Ababendoman	67,41	28.3	3.5	0	II
	Ngomedeng	50	36.6	6.7	6.7	OG
Bags	Nkonmedjap II	41,7	36,9	4,1	17,3	OG
	Abiété Yendjok	48,3	49,6	3,8	0	II
	Mbemang	26.6	33.3	23.3	16.7	OG
	Doumba'a zok	51,5	15,9	25,4	7,8	OG
	Ababendoman	74,7	21,6	3,4	0	II
	Ngomedeng	56,3	28,5	13,7	5,4	OG

L: clarity; C: saturation; h: hue angle. OG: Out of grade

4. Conclusion

This study shows that cocoa farmers are predominantly men made up of teenagers, adults and very few old people with an average secondary school level. These farmers cultivate cocoa farms under four production systems: small-scale cocoa farms (0.5-5ha) under shade and without external support; small-scale cocoa farms under shade with external support; small-scale cocoa farms without shade and with external support; and medium-scale cocoa farms (5-20ha).Very few producers correctly follow the order of post-harvest processing operations and the sorting of beans before fermentation is the most neglected operation by producers. Among the techniques used, the fermentation of cocoa beans in crates or in banana leaves, as well as their solar drying on elevated racks could be recommended to obtain good quality cocoa with better physical, morphological and physicochemical characteristics (moisture, lipids and acidity) leading to a commercial cocoa of grade I (superior) and II.

Consent

It is not applicable.

Ethical approval

It is not applicable.

Data Availability

The data used to support the findings of this study are available from the corresponding authors on request.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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