Journal of Agriculture and Ecology Research International

17(1): 1-10, 2018; Article no.JAERI.45924
ISSN: 2394-1073

Effect of Placenta and Fermentation Duration on Drying Dynamics of Cocoa Beans in a Tropical Environment

J. Amponsah[1], P. Kumah[1] and P. K. Tandoh[1*]

[1]Department of Horticulture, Kwame Nkrumah University of Science and Technology (KNUST), Ghana.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAERI/2018/45924
Editor(s):
(1) Dr. Maria Panitsa, Department of Environmental and Natural Resource Management, University of Patras, Greece.
Reviewers:
(1) Gideon Ramtahal Cocoa, The University of the West Indies, Trinidad and Tobago.
(2) Adeji Alaba Olaitan, Cocoa Research Institute of Nigeria, Nigeria.
Complete Peer review History: http://www.sdiarticle3.com/review-history/45924

Original Research Article

Received 13 October 2018
Accepted 19 December 2018
Published 18 January 2019

ABSTRACT

Cocoa is an important economic crop and has many uses industrially and locally. For its chocolate flavour to be obrained proper fermentation, drying and other postharvest practices needs to be done.
A study was conducted to examine the effect of placenta and varied fermentation periods on drying time and moisture reabsorption of cocoa beans from December, 2017 to January, 2018. Experimental design was 2×5 factorial of placenta inclusion or exclusion and varied fermentation days in CRD and replicated three times. Parameters studied included; drying time, weight loss, moisture reabsorption. The study revealed that placenta exclusion and fermenting for at least six days quickened the drying time (5 days) and boosted the mean bean weight of the cocoa beans. Also significantly maximum % moisture reabsorption (0.51%) was produced by cocoa beans with placenta fermented for eight days and the minimum (0.26%) was recorded by cocoa beans without placenta fermented for eight days. It was concluded that for the production of premium quality cocoa beans, fermentation should be done for, at least, six days without placenta since that reduced the time of drying significantly.

**Corresponding author: E-mail: paulusnow@gmail.com;*

Keywords: Moisture; reabsorption; capillarity; diffusion; weight loss.

1. INTRODUCTION

Cocoa (*Theobroma cacao L.*) meaning "food of the gods" in Greek, is a cash crop with massive economic significance in the world and doubles as the main raw material for chocolate production [1,2]. The crop is now cultivated in more than 50 countries on 0.2 per cent of the world's agricultural productive land. Currently it is one of the most domineering agricultural export commodities in the world. In 2016, the global chocolate market reached a value of 98.30 billion USD. Five countries alone accounted for 80% of the global production. Measured by capacity, the topmost five producers are Côte d'Ivoire (36%), Ghana (22%), Indonesia (11%), Nigeria (6%), and Brazil (5%) [3]. Ghana's Cocoa has superior quality specifications, attributable to excellent post-harvest handling procedures such as harvesting, pod storage, pod breaking, fermentation, drying, transportation and storage which some Ghanaian cocoa agronomists had maintained over the years. [4]. But of recent, Ghana's premium quality cocoa is grappling with such discrepant issues like suspected adulteration, black beans, presence of debris and foreign matter which may possibly be due to presence of placenta mottled with extracted cocoa beans during the process of fermentation and drying. According to International Cocoa Standards requirements, cocoa of tradable quality should be well fermented and thoroughly dried and free from any evidence of adulteration [5]. Folayan [6] explained that, the root cause of quality anomalies in cocoa could be traced to poor postharvest handling techniques which included addition of placenta during the bean extraction from the pod stage, bad fermentation including overly fermenting the beans coupled with inadequate drying or over drying. These bad practices make the produce vulnerable to mould and bacterial growth. In some cocoa producing communities in Ghana, the placenta is excluded from the fermentation process whereas in other communities it is included and later removed after the process of fermentation is accomplished, especially during the drying process. There is no clear cut guiding principle as to whether placenta should be included or excluded and when it should be done in the value chain of cocoa processing. Futhermore, placenta inclusion or exclusion can influence the effectiveness and duration of fermentation, the drying time, as well as the attendant labour cost in cleaning beans off placenta before or during drying period. Well fermented cocoa gives the best chocolate flavour and the presence of placenta could impact the microbial activities as well. Major research works on cocoa have concentrated on the roles fermentation and drying play on the quality of cocoa beans there is dearth of knowledge on the effect of presence or absence of placenta and fermentation duration on drying time of cocoa beans. The objective, therefore, of this study was to evaluate the effect of inclusion of placenta and varied fermentation periods on drying time and moisture reabsorption of cocoa beans in a tropical environment.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was conducted in the Bekwai Municipality of Ashanti Region. Bekwai municipal is one of the 30 administrative districts in the Ashanti Region. The municipal shares boundaries with Amansie West District to the west, Bosomtwe District to the north, Adansi south and North Districts to the south and the Asante Akim south District to the east. With a population of 208,987, and an intercensal growth rate of 3.2 percent males in the municipal constitute 52% while females constituting 48%. The rural population of the municipal is 8.4% while the urban population is 11.6%. Farming is the dominant occupation of the people in the municipal with cocoa farming being the main crop produced.

2.2 Experimental Design

A 2X5 factorial Completely Randomized Design with two experimental factors (Extracted cocoa beans with and without placenta) and five different fermentations duration (4 days, 5 days, 6 days,7 days and 8 days) which were replicated three times was used for the field experiment.

2.3 Sample Collection Procedure

2.3.1 Harvesting, sorting and pod storage or resting

Six hundred (600) cocoa pods of mixed hybrid variety which is translated to be equivalent to one bag of cocoa beans (62.5 kg) were harvested from a selected cocoa farm over a period of five days with 120 pods per day for the

experiment at Ashanti Bekwai. The riped pods on the cocoa tree stem were harvested using a well sharpened machete whiles fruits high up the tree were harvested using pruning hook or go to hell [7]. Debris, deseased infested and blemished pods were sorted out from the harvested stock in order to prevent them from being added to the experimental samples. Each daily harvested batch of pods (120 pods) were stored or rested for three days period as recommended by Sanagi et al. [8] before pod breaking process commenced.

2.3.2 Pod breaking and bean extraction

The one hundred and twenty harvested cocoa pods for the first batch treatment were divided into two equal groups, sixty (60) pods each and were opened for the beans to be extracted. Breaking of the pods were done using a blunt cutlass to expose the beans. This facilitated ease of bean-scooping from the pods. The mucilaginous beans from first 60 pods were extracted with placenta and replicated into three groups and the other remaining 60 pods were extracted without placenta and also replicated into three and were put on a plantain leaves for the fermentation process. This procedure was repeated for the subsequent harvested batches.

2.3.3 Fermentation method and process

The traditional heap fermentation method was used with varied fermentation periods (4 days, 5 days, 6 days, 7 days and 8days). In this method, cocoa beans were heaped on a bed of banana leaves with or without placenta. This was replicated into three groups and located at three different locations in the cocoa farm for the fermentation processs. The heap fermentation method was used because it is cheap, produces well fermented cocoa beans and is good for small production volumes [9]. This was followed up by the turning of the cocoa beans every two days to ensure even fermentation within every two days [7], until the end of the four to eight days.

2.3.4 Drying of fermented beans

Drying was done on a raffia mat at a cocoa depot sited in Bekwai. The drying raffia mat was raised one meter above ground and supported below with sawn bamboo sticks which facilitated movement of air around the platforms. Initial cocoa beans of mass 2.5 kg from each of the cocoa beans of varied fermentation period with or without placenta were weighed separately and put on the raffia mat for drying to commence. A space of dimension 100 cm x 50 cm square (ie drying Cell) was measured on the raffia mat This drying cell was replicated three times at different locations on the raffia mat of dimension 1000 cm x 200 cm square to create 30 different drying cells within which the drying of the treated cocoa samples were done.

Drying started from 8:00am to 5:00 pm each day. Beans were periodically stirred every three hours to ensure uniform drying. Drying continued until 7.5 to 6% moisture content was achieved.

Polyethene sheet was used to cover the beans on occasion of raining and sunset. A digital timer was used to time the drying process. Ambient Temperature and relative humidity (RH) of the environment were monitored using the data logger (RH range 5.0% to 95.0%).

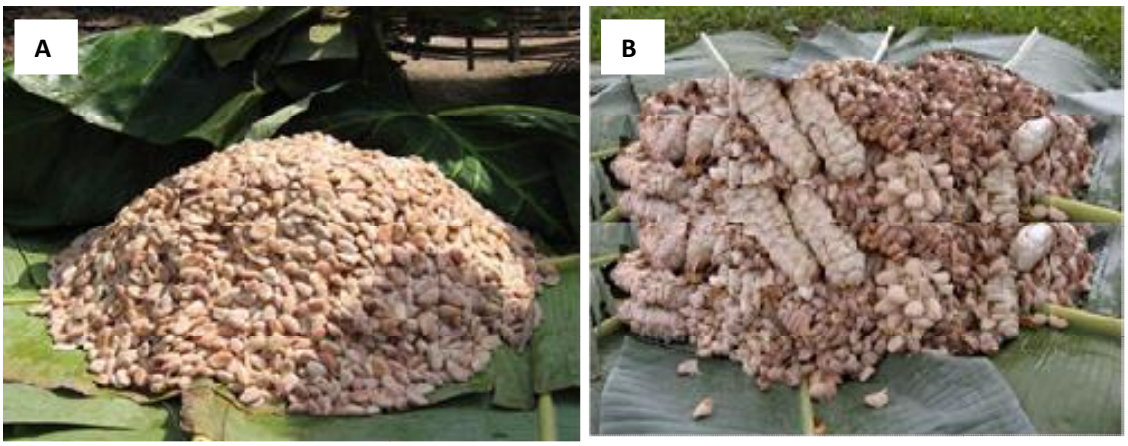

Plate 1. Cocoa beans extracted without placenta (A) with placenta (B)

Plate 2. Field layout and labels of beans undergoing fermentation in the cocoa farm

2.4 Parameters Measured

The following data were monitored and recorded during the drying period:

i. The initial moisture content as well as daily moisture content of the drying treated cocoa samples were measured every three-hour interval with an electronic moisture meter (KPM(Aqua-Boy) KAMIIIa-KIT (USA).
ii. The initial weight as well as the daily weight of the drying treated cocoa samples were determined every three-hour interval with an Electronic Table Top Weighing scale (silver Eagle) EX Tax 414(India)
iii. Daily ambient temperature and Relative Humidity of the drying environment were also determined from 6:00 am to 5:00 pm with a digital indoor and outdoor Hydro-thermometer (Extech 445713, USA).
iv. The number of days taken to achieve 7.5-6% moisture content of the cocoa bean sample were also monitored.

2.4.1 Drying time of the variedly fermented cocoa bean samples

The time (Days) taken for each of the variously fermented cocoa sample to dry from their initial moisture content value to the 7.5 -6% moisture level were monitored and recorded.

2.4.2 Cumulative moisture loss of the variously fermented cocoa bean samples

This was determined by measuring the dialy moisture content of the variously fermented cocoa bean samples undergoing drying with a moisture meter and the difference in moisture loss were expressed as a cumulative percentage of moisture loss from the initial moisture content of the cocoa bean samples [10].

2.4.3 Cumulative weight loss of the variously fermented cocoa bean samples

Cumulative weight loss of the variously femented cocoa samples were determined by weighing the cocoa bean samples daily and the difference in weight loss were expressed as a cumulative percentage of weight loss from the initial weight of the cocoa bean samples [10].

2.4.4 Moisture reabsorption rate of the variously fermented cocoa bean samples

This is the measure of the hydroscopic ability among the variedly fermented cocoa bean samples with or without placenta. It was based on how much moisture regained by the treated cocoa bean samples.

The daily moisture reabsorption rate was determined by subtracting the close of day moisture content of Cocoa sample (previous day) from moisture content of same cocoa sample at

the beginning of new day. These moisture regained by the cocoa samples were cumulated and expessed as a percentage.

This was expressed mathematically as:

Moisture Reabsorption rate =

$$\frac{\sum Mc\ New\ day(\%) - Mc\ Previous\ day(\%)}{Time(Days)}$$

Where

MC = Moisture Content of a Treated Cocoa Bean Sample

3. RESULTS

3.1 Ambient Temperature (°C) and Relative Humidity (%) of the Environment during the Drying of Cocoa Bean Samples

During the period of drying, the average maximum temperature was 49.2°C and the corresponding average maximum relative humidity of 90%. The average minimum temperature was 38.3°C and the average minimum relative humidity was 78% as shown Table 1. In all, the mean ambient temperature was 43.8°C with the associated relative humidity of 81%.

Table 1. Ambient temperature and relative humidity during drying of cocoa beans

Days	Temperature (°C)	Relative Humidity (%)
1	38.3	78
2	44.2	80
3	49.2	78
4	40..5	90
5	48.7	82
6	42.3	82
7	43.5	80
8	38.7	79
9	48.8	81
Mean	43.8	81

3.2 Drying Time (Days) of Cocoa Beans Fermented for Various Days with or Without Placenta

Drying time was significantly (p≤0.05) affected by fermentation days and placenta interaction (Table 2). Highest drying time was recorded by beans fermented for four days with and without placenta (9 days), whiles the least drying time was recorded by beans fermented for eight days without placenta (5 days). Among the fermentation days, highest drying time was recorded by beans fermented for four days (9 days) and the least was recorded by beans fermented eight days (5.50 days). Among the levels of placenta, beans dried with placenta had the highest drying time (7 days) and the least was without placenta (6 days).

Table 2. Drying time (Days) of cocoa beans fermented for various days with or without placenta

Fermentation days	Placenta		Mean
	With	Without	
4	9.00^{a*}	9.00^{a}	9.00^{a}
5	8.00^{b}	7.33^{c}	7.67^{b}
6	6.00^{d}	6.00^{d}	6.00^{c}
7	6.00^{d}	6.00^{d}	6.00^{c}
8	6.00^{d}	5.00^{e}	5.50^{d}
Means	7.00^{a}	6.67^{b}	
CV (%) = 2.67			

HSD (0.01) Fermentation days=0.31, Placenta=0.14, Fermentation days X placenta=0.14

** Means followed by the same alphabets are not significantly different (p≤0.05) from each other*

3.3 Cumulative Moisture Loss (%) of Cocoa Beans Fermented For Various Days with or Without Placenta

Cumulative moisture loss of dried cocoa beans were significantly (p≤0.05) affected by fermentation days and placenta interaction (Table 3). Highest cumulative moisture loss (54.72,54.83 and 54.72%) were produced by cocoa beans with placenta fermented for four,five and six days respectively and the least (54.06%) was recorded by beans with placenta fermented for eight days. Across the fermentation days, significantly (p≤0.05) highest cumulative moisture loss (54.62,54.69 and 54.60) were produced by cocoa beans fermented for four.five and six days and the least (54.21%) was recorded by those beans fermented for eight days. Across the Placenta, there were no significant differences (p≤0.05)in the cumulative moisture loss among the dried cocoa beans.

3.4 Cumulative Weight Loss (%) of Cocoa Beans Fermented for Various Days with or Without Placenta

The effects of varied fermentation days and placenta on Cumulative weight loss of dried cocoa beans are presented in Table 4 below. There were significant (p≤0.05) fermentation days and placenta interaction on cumulative

weight loss on the dried cocoa beans. The highest cumulative weight loss (60.00%) was produced by cocoa beans with placenta fermented for eight days whiles the least cumulative weight loss (49.20%) was recorded by beans without placenta and fermented for seven days. Across the fermentation days, significantly (p≤0.05) highest cumulative weight loss (56.4%) was produced by cocoa beans fermented for five and eight days and the least (50.80%) was recorded by beans fermented for six days. Across the Placenta, the highest cumulative weight loss (55.60%) was produced by beans with placenta and the least (52.40%) was produced by those without placenta.

Table 3. Cumulative moisture loss (%) of cocoa beans fermented for various days with or without placenta

Fermentation days	Placenta		Means
	With	Without	
4	54.72^{a*}	54.51^{ab}	54.62^{a}
5	54.83^{a}	54.55^{ab}	54.69^{a}
6	54.72^{a}	54.48^{ab}	54.60^{a}
7	54.43^{ab}	54.37^{ab}	54.40^{ab}
8	54.06^{b}	54.36^{ab}	54.21^{b}
Means	54.55^{a}	54.45^{a}	
CV (%)=0.40			

HSD (0.01) Fermentation days=0.38, Placenta=0.17, Fermentation days X placenta=0.63

** Means followed by the same alphabets are not significantly different (p≤0.05) from each other*

Table 4. Cumulative weight loss (%) of cocoa beans fermented for various days with or without placenta

Fermentation days	Placenta		Mean
	With	Without	
4	54.80^{bcd*}	54.00^{bcd}	54.40^{ab}
5	56.80^{ab}	55.60^{abc}	56.40^{a}
6	51.20^{cde}	50.80^{de}	50.80^{c}
7	54.40^{bcd}	49.20^{e}	52.00^{bc}
8	60.00^{a}	52.80^{bcde}	56.40^{a}
Means	55.60^{a}	52.40^{b}	
CV (%)=1.88			

HSD (0.01) Fermentation days=0.07, Placenta=0.03, Fermentation days X placenta=0.12

** Means followed by the same alphabets are not significantly different (p≤0.05) from each other*

3.5 Moisture Reabsorption (%) Rate of Cocoa Beans Fermented For Various Days with or Without Placenta

Moisture reabsorption of dried cocoa beans were significantly (p≤0.05) affected by fermentation days and placenta interaction (Table 5). Maximum % Moisture reabsorption (0.51%) was produced by cocoa beans with placenta fermented for eight days and the minimum (0.26%) was recorded by cocoa beans without placenta fermented for eight days. Across the fermentation days, the highest % Moisture reabsorption (0.41%) was produced by cocoa beans fermented for seven days and the least (0.37%) was recorded by beans fermented for five days. Across the Placenta, the highest % Moisture reabsorption (55.60%) was produced by beans with placenta and the least (0.32%) was produced by those without placenta.

Table 5. Moisture reabsorption (%) rate of cocoa beans fermented for various days with or without placenta

Fermentation days	Placenta		Mean
	With	Without	
4	0.48^{b*}	0.29^{g}	0.39^{bc}
5	0.42^{d}	0.33^{f}	0.37^{c}
6	0.43^{cd}	0.34^{f}	0.38^{b}
7	0.44^{c}	0.38^{e}	0.41^{a}
8	0.51^{a}	0.26^{h}	0.39^{bc}
Means	0.46^{a}	0.32^{b}	
CV (%)=1.76			

HSD (0.01) Fermentation days=0.01, Placenta=5.20, Fermentation days X placenta=0.02

** Means followed by the same alphabets are not significantly different (p≤0.05) from each other*

4. DISCUSSION

4.1 Placenta and Varied Fermentation Days on Drying Time (days) of Cocoa Beans

Drying of fermented cocoa beans is done mainly to reduce the moisture content of the cocoa beans in order to prolong the shelf life of the commodity, to halt fermentation,to reduce the water content in the bean and to drive out the acetic acid which was formed during fermentation [11]. Slow or delayed drying can cause off flavours from fungal or other deterioration. According to Afoakwa et al. [12] the ideal duration for a well fermented cocoa beans to dry to 7.5% should be between five to seven days. It is essential that cocoa bean dry to lower moisture level (7.5%) as quickly as possible regardless of the drying system employed in order to avoid initiation of moulding by Xerophilic Euritium species and ochratoxin production from *Penicillium verrucosum* and *Aspergillus ochraceus* (Magan et al. [13]). If

cocoa beans are not adequately dried, they are likely to go mouldy.Though too rapid drying rate could be bad as, in which case acetic acid will be trapped inside the beans, leading to a highly acidic end product) [14].

Takrama et al. [15] confirmed that Ochratoxin 'A'might develop in a contaminated cocoa beans like those with placenta inclusion whiles drying. This finding was later on confirmed by Amoa-Awua et al. [16]. Results from the current study showed that cocoa beans fermented for at least six days with or without placenta dried faster than those fermented for less than six days with or without placenta. This could be due to the fact that longer fermentation days' lead to rapid moisture loss which eventually reduced the time of drying. Ndukwu [17] reported on the effect of the drying air temperature and air velocity on the drying rate and drying constant of cocoa beans. He further stated that the more moisture that has been removed, the stronger the attraction to that remaining. Thus dryingis itself influenced by the amount of drying that has already taken place [18]. Moisture transfer to the surface of the drying solid occurs through various mechanisms including diffusion, capillarity, and internal pressures set up by shrinkage during drying. These factors possibly act in combination [19]. Anti [20] maintained that, bean mass, type of mat for drying and sunlight intensity were some of the key factors involved when it comes to fermentation perious and its effect on drying time. Anti [20] further revealed that the smaller the bean mass or the thinner the bean layer, the faster the drying time. the current study the presence of placenta added to the mass compared to those without placenta hence the longer drying period with respect to beans with placenta and fermented for less than six days. The more moisture thereis in the beans the longer it will take to remove them resulting in a longer drying period.

Furthermore, the weather condition prevailing at the period of drying the variously fermented cocoa beans also accelerated the rapidity of drying. The minimum temperature during the period was 38.3°C and the maximum was 49.2°C with a corresponding maximum and minimum relative humidity of 78% and 90% respectively. This assertion is supported by [21] who stated that the drying time of cocoa beans is largely determined by the ambient temperature and the relative humidity. Bharath and Bowen-O'Connor [22] also stated that the rate of drying of cocoa beans depends on; heat transfer into the bean, water transfer from within the bean to the air, humidity of the air, and surface area of the bean exposed to the air. This assertion has again been confirmed by Sukha [23].

4.2 Cummulative Moisture Loss of Cocoa Beans Fermented on Various Days with or Without Placenta

The result revealed that beans fermented for at least 4 days without placenta loss more moisture due to the fact that moisture loss from the product surface depended on drying air conditions while surface moisture conditions influence the mass transfer from the inside to the surface, [24]. The removal of moisture at the product-air interface depends on the temperatures of the product and drying medium, air humidity, air flow rates and volume pressure conditions, and the amount of product surface exposed to the drying medium [19].

The higher cumulative moisture loss by the cocoa beans with placenta fermented for less days could probably be due to the falling rate drying characteristics of cocoa beans as opined by Chinenye et al. [25]. Since those Beans dried with placenta had higher retention of moisture than those without placenta hence their rate of drying was quicker in accordance with the basic drying principles outlined by Doymaz [24] who stated that at the falling rate period of drying of cocoa beans, movement of moisture within the crop to the surface is governed by diffusion since the material is no longer saturated with water. However, Baryeh [26] stated that cocoa exhibits constant rate behaviour during drying, from moisture content of 70-7.5%; however, the in itial moisture content was not up to this range. But, too much moisture loss means reduction in weight leading to reduction in revenue.

4.3 Cumulative Weight Loss of Cocoa Beans Fermented on Various Days with or Without Placenta

Dried Cocoa bean is sold by weight .Excessive loss of weight will not be economical in terms of amount of money received by farmers. The study revealed that cocoa beans fermented for more than seven days with placenta recorded the highest cumulative weight loss compared to those without placenta fermented for seven days. This could be due to the positive moisture -

weight loss correlation. Mossu [7] revealed that weight of beans is directly related to its moisture and dry matter content.

Drying of the fermented cocoa beans reduces moisture content from 45% to 7% and as the moisture content within the beans reduces the weight also reduces. Bean weight is the quantity of matter that an individual grain contains. It includes the dry matter and the moisture present within the grains. However, the moisture present is dependent on the water holding ability of the grain and void spaces [7].

Weight of cocoa bean is a useful index to 'milling out turn' in measuring the relative amount of dockage or foreign material in a given lot of grain, and the amount of shriveled or immature beans [27]. The weight of grains has been found to increase linearly with an increase in moisture content for barley grains [28].

The cumulative loss in weight among the cocoa bean with placenta were influenced by the fermentation days and placenta inclusion. This could probably be due to moisture availability provided by placenta and shorter days in fermentation. Adu et al. [29] stated that cocoa mucilage together with its placenta consists of about 87% water content.

In order to obtain beans with optimum weight, cocoa beans without placenta should be fermented for at most seven days.

4.4 Moisture Reabsorption of Cocoa Beans Fermented On Various Days with or Without Placenta

Cocoa beans dried with placenta had the highest rate of moisture reabsorption. This could be due to the presence of placenta which served as moisture reservoir [29] for the beans which had already lost some amount of moisture due to its hygroscopic nature [14]. Garg et al. [30] revealed in their study that, a product's resistance to internal moisture loss depends on its hygroscopic and colloidal properties as well as the size of the pores, which govern the capillary movement of fluid. Beans with placenta has a higher hygroscopic and colloidal properties than cocoa beans fermented without placenta hence high moisture reabsorption capacity.

Sanagl et al. [8] also revealed that moisture transfer to the surface of the drying solid occurs through various mechanisms including diffusion, capillarity, and internal pressures set up by shrinkage during drying. These factors possibly act in combination according to Mujumdar and Menon [19].

Cocoa beans are highly hydroscopic particularly when it is mottled with placenta [13]. That is, they can reabsorb moisture during storage and transport resulting in mould growth which can cause *Aspergillus ochraceus* establishment and contaminate beans with harmful ochratoxins [31].

5. CONCLUSION

The study revealed a high cumulative loss in weight of cocoa bean sample treated with placenta. For least weight loss of cocoa beans they should be fermented for at least six days without placenta. For drying wet cocoa to low moisture quite rapidly, beans should be femented without placenta for at least six days. Beans with placenta had the highest rate of moisture reabsorption at storage hence to avoid high hydroscopic activity of drying cocoa, placenta inclusion during bean extraction and fermentation should be discouraged. For the best in achieving quickest optimum drying duration, at least six days of fermentation of a well riped cocoa beans extracted without placenta should be adopted.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Krähmer A, Engel A, Kadow D, Ali N, Umaharan P, Kroh LW and Schulz H. Fast and neat–Determination of biochemical quality parameters in cocoa using near infrared spectroscopy. Food Chemistry. 2015;181:152-159.
2. Ho VTT, Zhao J, Fleet G. The effect of lactic acid bacteria on cocoa bean fermentation. International Journal of Food Microbiology. 2015;205:54–67.
3. ICCO (International Cocoa Organization). Assessment of the Movement of Global Supply and Demand. Market Committee, 6th meeting. Exists as a download file at http:// www. icco. org/economics/ consultive.aspx in cocoa and chocolate: A critical review. Critical Reviews in Food Science and Nutrition, Inc. Oxford, U.K. pp. 457 – 468 Indonesia. Int. J. Food

Microbiol., 86: 87- 99. Industrial Crops Products 24: 87–94. International Journal Food Microbial. 2007;114:124-130.

4. Binam J, Gockowski J, Nkamleu G. Technical efficiency and productivity potential of cocoa farmers in West African countries. The Development Economies, XLVI-3. 2008;242–263.
5. Afoakwa EO, Paterson A. Cocoa fermentation: Chocolate flavour quality. Encyclopedia of Biotechnology in Agriculture and Food. Taylor & Francis Publishing Inc. Oxford, UK. 2010;457-468.
6. Folayan JA. Nigerian cocoa and cocoa by-products: Quality parameters, specification and the roles of stakeholders in quality maintenance. Pakistan Journal of Nutrition. 2010;9(9):915-919.
7. Mossu G. Cocoa. The tropical agriculturalist. London, England. Motamayor, J. C., Risterucci, A. M., Lopez, P. A., Ortiz, C. F., Moreno, A. and Lanaud, C. (2002). Cacao domestication I: The origin of the cacao cultivated by the Mayas. Heredity. 1992;89(5):380.
8. Sanagi MM, Hung WP, Md Yasir S. Supercritical fluid extraction of pyrazines in roasted cocoa beans – Effect of pod storage period. Journal of Chromatography. 1997;785:361-367
9. Doyle MP, Beuchat LR, Montville TJ. Cocoa and coffee. Food Microbiology. 2001;720e733.
10. Nirupama P, Neeta B. Gol, Ramana Rao TV. Effect of post-harvest treatments on physicochemical characteristics and storage life of tomato (*Lycopersicon* esculentum Mill). Fruits during Storage. American-Eurasian Journal Agricultural and Environmental Science. 2010;9(5): 470-479.
11. Di Mattia C, Martuscelli M, Sacchetti G, Scheirlinck I, Beheydt B, Mastrocola D, Pittia P. Effect of fermentation and drying on Procyanidins, Antiradical Activity and reducing properties of cocoa beans. Food and Bioprocess Technology. 2013;6(12): 3420–3432.
12. Afoakwa EO, Quao J, Takrama J, Budu AS, Saalia FK. Effect of pulp preconditioning on acidification, proteolysis, sugars and free fatty acids concentration during fermentation of cocoa (*Theobroma cacao*) beans. International Journal of Food Sciences and Nutrition. 2011;62(7):755–764.
13. Magan N, Sanchis V, Aldred D. Role of spoilage fungi in seed deterioration. Fungal Biotechnology in Agricultural, Food and Environmental Applications. 2004; 311-323.
14. Wood GAR, Lass RA. Cocoa, 4th ed. Longman Group Limited, London; 1985.
15. Takrama JF, Aculey PC, Aneani F Fermentation of cocoa with placenta: A scientific study. Posters presentation. Chemistry, technology and quality. In 15th International Cocoa Research Conference; 2007.
16. Amoa-Awua WK, Sampson E, Tano-Debrah K Growth of yeasts, lactic and acetic acid bacteria in palm wine during tapping and fermentation from felled oil palm (*Elaeis guineensis*) in Ghana. Journal of Applied Microbiology. 2007; 102(2):599-606.
17. Ndukwu MC. Effect of drying temperature and drying air velocity on the drying rate and drying constant of cocoa bean. Agricultural Engineering International: CIGR Ejournal. Manuscript 1091. 2009;XI.
18. Keey RB. Introduction to industrial drying operations. Kinetics of the formation of free amino acids in cocoa seeds during fermentation. Food Chemistry. 1978;34: 161-179.
19. Mujumdar AS, Menon AS. Drying of solids: principles, classification, and selection of dryers. Handbook of Industrial Drying. 1995;1:1-39.
20. Anti EO. Effects of two different drying mats at different loading densities on the physical and chemical qualities of cocoa beans MPhil dissertation; 2014.
21. Fagunwa AO, Koya OA, Faborode MO Development of an intermittent solar dryer for cocoa beans. Agricultural Engineering International: CIGR Journal; 2009.
22. Bharath S, Bowen-O'Connor C. (Assessing drying rates of cacao beans using small samples. Cocoa Research Unit the University of the West Indies. 2008;52.
23. Sukha DA. Innovations in solar drying of the fine or flavour cocoa bean. The cocoa research unit. Presentation from "Cocoa sector Technical forum", Kingston and St. Mary, Jamaica; 2009.
Available:http://sta.uwi. edu/cru/
24. Doymaz I. Drying characteristics and kinetics of okra. Journal of food Engineering. 2005;69(3):275-279.
25. Chinenye NM, Ogunlowo, AS, Olukunle, OJ. Cocoa *bean (Theobroma cacao* L.)

drying kinetics. Chilean Journal of Agricultural Research. 2010;70(4):633-639.

26. Baryeh E. Cocoa drying and storage using charcoal and solar heated rocks. Agricultural Mechanization in Asia, Africa and Latin America. 1985;16(1):23-28.
27. Saiedirad MH, Tabatabaeefar A, Borghei A, Mirsalehi M, Badii F, Varnamkhasti MG. Effects of moisture content, seed size, loading rate and seed orientation on force and energy required for fracturing cumin seed (*Cuminum cyminum* Linn.) under quasi-static loading. Journal of Food Engineering. 2008;86(4):565-572.
28. Tavakoli M, Tavakoli H, Rajabipour A, Ahmadi H, Gharib-Zahedi SMT. Moisture-dependent physical properties of barley grains. International Journal of Agricultural and Biological Engineering. 2010;4:84-91.
29. Adu MO, Cobbinah T, Asare PA, Yawson DO, Taah KJ. Demucilaging freshly stored seeds of cocoa (*Theobroma cacao* L.) improves seedling emergence and growth. Journal of Botany; 2017.
30. Garg HP, Datta G, Bhargava, AK. Performance studies on a finned-air heater. Energy. 1989;14(2):87-92.
31. Cairns-Fuller V, Aldred D, Magan, N. Water, temperature and gas composition interactions affect growth and ochratoxin A production by isolates of *Penicillium verrucosum* on wheat grain. Journal of Applied Microbiology. 2005;99(5):1215-1221.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle3.com/review-history/45924