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Quality evaluation of cocoa beans at various quantities and duration of basket fermentation

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ABSTRACT

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The study aimed to determine the influence of basket fermentation on the quality of cocoa beans with various quantities and duration of fermentation. Proper fermentation and drying removes all unpleasant flavours and starts the chemical changes necessary to produce the true cocoa and chocolate flavours that emerge after roasting. Basket fermentation offers a cheap practical method for small-scale farmers to process their cocoa beans. This study was conducted to determine the effect of basket fermentation on the quality of cacao beans using different quantities of beans and duration of fermentation. This was laid out in a Completely Randomized Design with ten (10) treatments each with three (3) replications. Data gathered were analyzed using Analysis of Variance (ANOVA). Means of significant results were compared using Tukey's Honest Significance Difference (HSD) Test.

The results revealed significant differences on the quality of processed cacao beans in terms of percentage of fully fermented beans, under-fermented beans, slaty beans, moldy beans, defective beans, pH and titratable acidity. The ideal quality, grade 1A, was attained after 5 days with 25kg and 50kg of cocoa beans per basket and 7 days duration with 50kg of cocoa beans. In addition, flavour attributes are dependent on the duration and quantity of cocoa beans in basket fermentation. The study shows significant results on the sensory evaluation of the chocolate and bitterness flavour attributes. However, the quantity and duration of basket fermentation does not influence the sourness and astringency of the cocoa liquor. Fermentation for five (5) days with fifty (50) kg cocoa beans was found to be the most profitable treatment.

Keywords: Cacao, basket fermentation, duration, fermentation, physical quality, sensory evaluation

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INTRODUCTION

Cacao *(Theobroma cacao* L.*)* is one of the world's valuable crops that is cultivated worldwide on 8.2 million hectares, grown in 58 countries and worth over 4 billion USD annually. Cocoa beans are the seeds obtained from cocoa pods that are an essential source of cocoa butter and the raw ingredients for the manufacturing of chocolates, cakes, biscuits, ice cream and candy products.

The raw cocoa beans usually have an unpleasant flavor and need to undergo subsequent treatments such as fermentation, drying and roasting in order to obtain desirable sensory characteristics (Wood & Lass 2001). The fermentation of cocoa beans is important for the development of cocoa flavor precursors and termination after the correct duration will ensure the production of the best quality of dried cocoa beans (Khairul 2005). Export prices of cocoa beans are dependent upon quality. Premium high quality cocoa beans give the farmers premium prices on the world market. Indications of good quality are whole, well-ripe, well-fermented and well-dried beans (Mikkelsen 2010).

In the Philippines, large volumes of cocoa production can be found in the municipalities of Asuncion, Kapalong and San Isidro, in the province of Davao del Norte. The majority of the farmers are smallholders that own cacao farms with an average of 1-3 hectares (Magallon et al 2022). However, cacao beans produced in these areas are not well fermented. The usual practice of the cacao growers is to ferment the beans in sacks overnight. These sacks are tightly tied producing anaerobic fermentation. This is done to allow the sweatings to drain and reduce the mucilage for easy drying. The dried cacao beans are usually sold to local traders and other farmers sell their wet beans to the processors or consolidators in the locality.

Usually, fermentation is done in heaps, wooden boxes or in baskets. On cocoa plantations, this is carried out in wooden boxes that can hold one to two tons of cocoa beans. For smallholders with relatively small volumes of produce, basket fermentation is the most appropriate (Espino & Ramos 2008) as baskets can be sourced within the locality, resulting in lower production costs. In the next five (5) years, cacao production in the area is expected to increase considerably as massive planting of cacao had been initiated and supported by various government agencies for the last two (2) to three (3) years. The local market opportunities for "*tablea*" and cocoa products is growing as there is an increasing number of cafes and restaurants offering chocolate drinks. The demand for cocoa in the international market likewise is increasing and demands high quality cocoa beans. Hence, in order to attain good quality cocoa beans, innovative fermentation needs to be introduced to the local cacao farmers in the Philippines.

There are no studies conducted yet by researchers in the region or in the province for the performance of basket fermentation. The conduct of this study, therefore, aimed to determine the effect on the quality of cacao beans in Davao del Norte with basket fermentation using different quantities of beans and duration of fermentation.

MATERIALS AND METHODS

Time and Place of the Study

The study was conducted in San Isidro, Davao del Norte. This Municipality is one of the major producers of cacao beans in the province. It was conducted during the peak period of cacao harvest in November 2016 to April 2017.

Treatments and Layout

The study was laid out in a Completely Randomized Design (CRD) with 10 treatment combinations replicated three (3) times per treatment. The treatment combinations were:

T_1	25kgs of cocoa beans with 3 days fermentation
T_2	50kgs of cocoa beans with 3 days fermentation
T_3	75kgs of cocoa beans with 3 days fermentation
T_4	25kgs of cocoa beans with 5 days fermentation
T_5	50kgs of cocoa beans with 5 days fermentation
T_6	75kgs of cocoa beans with 5 days fermentation
T_7	25kgs of cocoa beans with 7 days fermentation
T_8	50kgs of cocoa beans with 7 days fermentation
T_9	75kgs of cocoa beans with 7 days fermentation
T_{10}	Conventional, 50kgs in sacks with 1 day fermentation.

Preparation of Cocoa Beans for Fermentation

The study used mixed varieties of cocoa consisting of UF 18, BR 25 and unidentified trinitario hybrid since single varieties could rarely be found on the farms due to the self-incompatibility issues of cacao trees. Cacao pods of these hybrids were harvested when they attained at least 50% ripeness. These were identified by the change of color of the cacao pods from green to yellow and red to orange. Sorting of the pods was done by separating infested, diseased and unripe pods from the clean pods. Breaking of cacao pods was done using a wooden mallet to ensure that the beans were not damaged. Beans were scooped out from the pods using hands. Germinated and infested beans were separated.

Fermentation of Cocoa Beans

A fermentation shed made with '*nipa*' palm leaves as roofing and bamboo for the flooring at a height of at least one meter above the ground was established

prior to the experimental set-up. This is where the baskets loaded with cocoa beans for fermentation were placed. Cocoa beans from the field were directly placed into 528x365x324mm plastic crates and allowed to stand overnight to drain the sweating pulp, thus reducing the acidity of the pulp. The following day, mixing of the cocoa beans from the different farms was done. Cocoa beans were then transferred to the 520x325x280mm bamboo baskets lined with banana leaves for each specific treatment. Baskets were covered by banana leaves and these were covered by plastic sacks to ensure that enough heat was generated during fermentation. The bottom of the baskets remained uncovered to allow sweating and further draining. Turning of the beans by reversal was done on the second day and every two days thereafter. Empty baskets were provided for the reversal of the beans. Initial data of the temperature and pH of the beans in the baskets were taken using a thermometer and pH meter (Oakton PH550), respectively prior to fermentation. Subsequent recording of pH and temperature of the beans were taken on the second day of fermentation and every two days thereafter.

Drying of the Beans

The beans were dried on 500x200x8cm bamboo trays with a fine PE netting base after the fermentation process. Drying of the beans was done according to the different treatments. Freshly fermented beans were spread onto the bamboo trayst at a depth of at least five centimeters and dried under the sun. Cocoa beans were mixed at hourly intervals to promote uniform drying and to breakup the conglomerates. The drying of the cocoa beans was continued until the moisture content of at least 7% was attained. After drying, hand sorting of the cocoa beans was done to eliminate flat beans and other foreign materials.

Cut Test

The cut test of Guehi et al (2010) was used, with some modification, for the evaluation of the sanitary and fermentation quality of the beans. One hundred pieces of dried cocoa beans were randomly taken from each experimental unit for the cut test. The cocoa beans were cut lengthwise through the middle to expose the maximum cut surface of the cotyledons. The halves of each bean were then examined in full daylight. Brown, purple and defective beans were counted and the percentage of each category was computed. Defective beans included infested, moldy and germinated beans.

Preparation of Cocoa Liquor

Three hundred grams of cocoa beans were taken from each experimental unit and roasted in preparation for production of cocoa liquor. The cocoa beans were roasted in stainless steel wok over a low fire at 250-325F (120C) for two hours. After roasting, the cocoa beans were deshelled and cleaned. The cleaned cocoa nibs were subjected to grinding, and were molded into tablet forms, locally known as '*tablea'*, that were used for cocoa liquor preparation. The cocoa nibs are crushed until the friction of the grinding process transforms them into a liquid paste called cocoa liquor (Mendez et al 2019).

Sensory Evaluation

The prepared cocoa liquor was collected in a total of thirty (30) containers. Each was labelled according to its treatment. Briefing and orientation to the panelists was done prior to the sensory evaluation of the cocoa liquor. Sensory attributes, such as appearance, odor, flavor, taste, and texture of foods detectable by human senses, are often used to evaluate food quality. These characteristics may also serve as references during the selection of foods (Lyon & Lyon 2001). The panelists were composed of two Municipal/City Agriculturists, two Municipal Research Coordinators, two Senior Agriculturist, two Agriculturist I from Provincial Agriculture Office (PAGRO), and two students. The age of the panelists ranged from 20 to 59 years old, and all of them were cocoa enthusiasts. Each panelist was asked to inhale the aroma volatiles, taste the cocoa liquor and caste their judgment on the evaluation sheet given to them. They were asked to rinse their mouths with water after tasting each sample.

The sensory scaleof Potts (2010) was used during the sensory evaluation of attributes such as cocoa flavor, astringency, bitterness and sourness with some modifications. These were: 0–No taste attributes detected; 1–Threshold, just barely perceptible, below recognition; 2-Slight; apparent and recognizable-low level; 3-Slight to moderate; apparent and recognizable; 4-Moderate/obvious, clearly noticeable; 5-Moderate to strong/nearly overpowering; and 6-Strong/overpowering and dominating.

The following 9-point hedonic scale was used for aroma and acceptability: 1-Dislike Extremely; 2-Dislike Very Much; 3-Dislike Moderately; 4-Dislike Slightly; 5-Neither Like nor Dislike; 6-Like Slightly; 7-Like Moderately; 8-Like Very Much; 9 - Like Extremely.

Data Gathered

The percentages of fully fermented and under fermented beans indicated by brown and purple color, respectively were taken from the one hundred sample of beans from each experimental unit. The percentages of slaty beans having the characteristics of rubbery cotyledon, resistance to cutting, and grayish in color, the moldy beans and defective beans such as germinated and infested beans were taken from the one hundred sample beans from each experimental unit. The temperature at initial and every two days during fermentation was recorded. The pH data was gathered and recorded before and after fermentation. This was done by immersing a pH meter into the cocoa bean mass for sixty (60) seconds. Bean count was carried out by the determination of cacao beans to make a weight of 100g. Three hundred dried cocoa beans were randomly taken from each treatment. The results of the fermentation quality of each treatment were graded accordingly based on the Philippine National Standard for Cacao (PNS/BAFPS No. 58:2008). Sensory quality was determined based on the result of the sensory evaluation conducted. Sensory attributes such as cocoa flavor, astringency, bitterness and sourness were rated and presented. Aroma acceptability was likewise determined using 9-point hedonic scale. The production costs incurred for each treatment were recorded. The gross income and net income of the fermented beans using various treatments were also determined.

Samples of dried cocoa beans from each treatment were submitted to the Science Resource Center, University of Immaculate Concepcion (UIC), Davao City

for chemical analysis. The Cocoa Beans'Grade was based on the Philippine National Standard on Cacao or Cocoa Beans specification (Appendix A).

Total Titratable Acidity

The total titratable acidity (TA) was determined by titrating the sample with a standard base. Five mL of sample was titrated after adding 50mL of distilled water. Two to three drops of phenolphthalein indicator were added with standard base (0.1N NaOH) to a faint pink color. Sampling was done per treatment. The percent TA was then computed from the amount of NaOH consumed to reach the end point (AOAC International 2005). The following formulas were used:

$$\%TA = \frac{(T-B) \times NNaOH \times AF \times 100}{mL \text{ or } g \text{ sample} \times DF}$$

T = Volume of NaOH used to titrate the sample, mL
B = Volume of NaOH used to titrate the blank, mL NNaOH = Normality of NaOH used, meq mL-1
AF = Acid Factor, g meq-1
DF = Dilution Factor (mL aliquot mL-1 of diluted sample)

Statistical Analysis

Data were analyzed using ANOVA (Analysis of Variance) to test the significance of the result. Tukey's Honest Significance Difference test was then performed to compare means of significant results

RESULTS AND DISCUSSION

Table 1 presents the mean percentage of fully fermented, under fermented, slaty, mouldy, defective and over fermented cocoa beans as influenced by the different quantities and durations of basket fermentation. Figure 1 shows the quality of cocoa beans as influenced by the different quantities and durations of basket fermentation.

Table 1. Cut test of cocoa beans as influenced by the different quantities and durations of basket fermentation

Treatment	Mean Percentage**					
	Fully Fermented	Under Fermented	Slaty Bean	Mouldy Bean*	Defective Bean*	Over Fermented Bean
T_1	55.70^{bc}	33.70^{ab}	9.70^{bcd}	0.00^{b}	1.00^{ab}	0.00^{b}
T_2	47.00^{c}	36.30^{a}	16.00^{bc}	0.33^{ab}	0.33^{ab}	0.00^{b}
T_3	43.30^{c}	35.00^{a}	20.00^{b}	1.67^{ab}	0.00^{b}	0.00^{b}
T_4	87.00^{a}	9.30^{cd}	3.00^{cd}	0.33^{ab}	0.33^{ab}	0.00^{b}
T_5	88.70^{a}	7.70^{de}	2.00^{d}	0.67^{ab}	1.00^{ab}	0.00^{b}
T_6	64.00^{abc}	19.30^{bc}	16.00^{bc}	0.33^{ab}	0.33^{ab}	0.00^{b}
T_7	70.00^{abc}	3.70^{de}	3.33^{cd}	3.33^{a}	1.67^{a}	13.30^{a}

*Significant at 5% level
**Highly Significant at 1% level
Means having the same letter superscript are not significantly different with each other at 5% level of significance

Table 1 continued

Treatment	Mean Percentage**					
	Fully Fermented	Under Fermented	Slaty Bean	Mouldy Bean*	Defective Bean*	Over Fermented Bean
T_8	81.30^{ab}	2.00^{e}	3.00^{cd}	1.00^{ab}	1.00^{ab}	11.70^{ab}
T_9	68.00^{abc}	12.00^{cd}	6.70^{bcd}	1.00^{ab}	1.67^{a}	9.70^{ab}
T_{10}	12.70^{d}	21.70^{abc}	64.70^{a}	0.33^{ab}	0.67^{ab}	0.00^{ab}
CV (%)	12.01	14.65	23.99	35.49	19.96	59.69

Percentage of Fully Fermented Cocoa Beans

Data showed that 5-day fermentation duration of 50 kilograms cocoa bean (T_5) obtained the highest percentage at 88.7% and this is comparable to 25-75kgs beans at 5-7 days fermentation (Table 1). The conventional method (T_{10}) got the lowest percentage of fully fermented beans at 12.7%. This conforms to the study of Khairul Bariah (2014) that the highest percentage of fully brown beans (82%) was observed on five (5) day fermentation. Adequately fermented beans can be obtained from five (5) days fermentation period in a basket or in fermentation box as specified in the Philippine National Standards. According to SIRIM (2005) as supported by Guehi et al (2010), if cut test results have fully brown beans for more than 60%, the dried cocoa beans (in batch) are considered good quality. However, 75 kilograms of cocoa beans in 5 days fermentation (64% brown beans) failed to pass the bean grading due to its high percentage of slaty beans. This might be attributed to the overcrowding of beans in the basket that caused poor aeration.

Figure 1 shows (from left to right: T_1-25kgs of cocoa beans in 3 days fermentation; T_2-50kgs of cocoa beans in 3 days fermentation; T_3-75kgs of cocoa beans in 3 days fermentation; T_4-25kgs of cocoa beans in 5 days fermentation; T_5-50kgs of cocoa beans in 5 days fermentation; T_6-75kgs of cocoa beans in 5 days fermentation; T_7-25kgs of cocoa beans in 7 days fermentation; T_8-50kgs of cocoa beans in 7 days fermentation; T_9-75kgs of cocoa beans in 7 days fermentation; and T_{10}-Conventional, 50kgs in sacks for 1 day fermentation).

Figure 1. Quality of cocoa beans as influenced by different quantities and durations of basket fermentation.

Figure 1 continued

Percentage of Under Fermented Cocoa Beans

The highest percentage of under fermented beans as indicated by purple beans was observed after 3 days fermentation duration (25kgs, 50kgs, 75kgs) at 33.7, 36.3 and 35.0%, respectively which were comparable to the conventional method (50kgs for one day fermentation). According to Guehi et al (2010), purple beans or under fermented cocoa beans occur when the fermentation has been terminated prematurely. The International Cocoa Organization (2008) cited that the fermentation process begins with the growth of microorganism. In particular, yeasts grow on the pulp surrounding the beans. Insects, such as the drosophila melanogaster or vinegar fly, are probably responsible for the transfer of microorganisms to the heaps of beans. The yeast converts the sugar in the pulp surrounding the beans to ethanol. Bacteria then start to oxidise the ethanol to acetic acid and then to carbon dioxide and water producing more heat and raising the temperature. The pulp starts to break down and drain away on the second day. Lactic acid bacteria convert the alcohol to lactic acid in anaerobic conditions but, as the acetic acid bacteria more actively oxidize the alcohol to acetic acid, when conditions become more aerobic the activity of lactic acid bacteria is halted. The temperature is raised to 40°C-45°C during the first 48 hours of fermentation. In the remaining days, bacterial activity continues under increasing aeration conditions as the pulp drains away and the temperature is maintained. The process of turning or mixing the beans increases aeration and consequently bacterial activity. The acetic acid and high temperature kill the cocoa beans ability to germinte by the second day. On the contrary, the 7 days fermentation duration of 50kgs cocoa beans attained the lowest percentage of under fermented beans at 2% (Table 1). Results also showed that longer fermentation at 5-7 days had lower under fermented beans than 3 days fermentation. Fermentation periods from five (5) to seven (7) days are typical farmer's practices in Davao region. According to the study by Guehi et al (2010) cocoa fermented for six (6) days had better commercial value, better chemical quality in terms of acidity than those obtained after 4 and 5 days of fermentation whatever the process used.

Percentage of Slaty Cocoa Beans

The conventional method (T_{10}) gave the highest average percentage of slaty beans at 64.7% while the lowest percentage of slaty beans (2%) occurred after 5 days fermentation duration at 50kgs of cocoa beans per basket (T_5) (Table 1). This study agrees with the findings of Kengor et al (2013) that the percentage of slaty beans was higher in the unfermented beans (conventional method). Slaty beans have the characteristics of rubbery cotyledon, resistance to cutting, and greyish in color. Based on the Philippine National Standard for Cacao (PNS/BAFPS No. 58:2008), cacao grades 1A-B have 3% slaty beans while grades 2A-B have 8% slaty beans while more than 8% slaty beans are sub-standard.

Percentage of Moldy Cocoa Beans

The highest average percentage of moldy cocoa beans at 3.33% was observed after 7 days fermentation period with 25kgs (T_7) (Table 1). This is because the temperature of the 25kgs cocoa beans had decreased on the fifth day of fermentation to 35.3°C (Table 4). If the temperature drops below 40°C from day 4

onwards, the cocoa should be immediately placed on the dryer, otherwise, the cocoa will develop “off flavors”. The rest of the treatments appeared to have an average percentage of moldy beans of less than 2%. Based on the Philippine National Standard (PNS/BAFPS: 58:2008), having a 3% maximum of moldy cacao beans is considered good quality cacao beans.

Percentage of Defective Cocoa Beans

Defective beans are the sum of germinated beans, infested beans and flat beans. The highest average percentage of defective cocoa beans(1.67%) was observed in two treatments both after 7 days fermentation period at 25kgs and 75kgs (T_7 &T_9). Other treatments resulted in 1% defective and below (Table 1). Based on the Philippine National Standard (PNS/BAFPS: 58:2008), all of the treatments have defective beans while grades 2A-B have 5% defective beans while more than 5% defective beans is sub-standard.

Percentage of Over Fermented Cocoa Beans

The study showed that the 7 days fermentation periodwith 25kgs (T_7), 50kgs (T_8) and 75kgs (T_9) produced over fermented beans (Table 1). This conforms with the Philippine National Standards that too long fermentation (>5 days fermentation) results to over fermented beans. There were no over fermented cocoa beans with the shorter fermentation days.

Reed (2010) states that extended fermentation causes a sharp rise in the bean's pH and the formation of ammonia, causing what some consider unfavorable high fermentation flavour notes. The color of the beans will also begin to darken beyond brown; this drastic change in bean flavor and color can symbolize the beginning of spoilage. When fermentation is too long, the following flavors can result: Acetic – a fermentation flavour characterized by the aromatic of distilled white vinegar. A reference for acetic is the flavour of a 10% vinegar (acetic acid) water solution; Cheesy-general – the aromatic associated with indistinguishable acidic cheese. A reference for cheesy general is the flavour of cheddar cheese spread; Fermented fruit/Winey – the aromatic reminiscent of the non-descript fruit note in red wine. A reference is the flavour of the communion wine in 5% vinegar solution; Putrid – the reference characteristic aromatic of rotten fruit. Putrid is an unpleasant flavor associated with end products of alcoholic and bacterial fermentations. A reference for putrid is the flavour of a 50:50 red wine vinegar water solution; Sour – the basic taste stimulated by acids. During fermentation sour flavors peak and begin to tail off. A reference for sour is the flavour of 0.08% citric acid/water solution; Straw – the aromatic associated with dried grain stalks. A reference for straw is the aroma of straw or unfiltered, unflavoured cigarettes; Yeasty – the aromatic associated with yeast and yeast-containing products. A reference for yeasty is the aroma of bread yeast hydrated in hot water. According to the study of Vázquez-Ovando et al. (2015); the highest sensory quality of cocoa is associated with descriptors of sweet taste, less bitterness and chocolate and hazelnut odors. Conversely, the low quality cocoa is associated with bitter taste and off-odors.

pH of Cocoa Bean During Fermentation

The initial pH value of fresh cocoa beans before fermentation in all treatments was observed to be high ranging from 5.7 to 6.1 as shown in Table 2. On the second day (48 hours) after fermentation, the pH of the beans lowered to as low as 4.5. The decline of the pH values were also observed by other researchers such as Biehl (1984), Khairul Bariah (2005, 2014), Shamsuddin et al (1978) and Said et al (1988). Biehl (1984) mentioned that the diffusion of acids (predominantly acetic acid) occurs during fermentation to decrease the pH of the cotyledon. Afoakwa et al (2011) added that the decrease of pH is a result of the microbial activity that happens during fermentation that produces ethanol and organic acids mainly acetic acid that cause the death of cotyledon. Subsequent chemical reactions take place that cause the chocolate flavor and color to develop.

For all of the treatments, the pH increased on the 4th day except for the 5 days duration with 75kgs cocoa beans when the pH reduced from 4.5 to 4.4. This conforms with the study of Khairul Bariah (2014) that fresh cocoa beans had a pH value of 6.38 at the beginning of fermentation. As fermentation proceeds, the pH value dropped to 4.43 on the third day and slightly increased towards the end of fermentation.

Table 2. pH of cocoa beans during fermentation as influenced by different quantities and durations of basket fermentation. Note that no pH data (Blanks in Table) were taken on some treatments after the duration of fermentation

Treatment	Initial	2nd Day	4th Day	6th Day
T_1	5.90	4.60	-	-
T_2	6.00	4.50	-	-
T_3	5.70	4.70	-	-
T_4	5.80	4.90	4.90	-
T_5	6.10	4.50	5.00	-
T_6	5.90	4.50	4.40	-
T_7	5.90	4.60	5.10	5.00
T_8	6.00	4.60	5.00	4.90
T_9	5.80	4.70	5.00	4.40
T_{10}	5.90	-	-	-

Temperature (°C) of Cocoa Beans During Fermentation

The initial temperatures of the cocoa beans in all treatments are almost the same ranging from 20.2-20.4°C as shown in Table 3. The temperature increased rapidly from the initial loading of beans to as high as 42.3°C at 7 days fermentation period in 25kgs at second day. According to Schwan and Wheals (2004), increase in the temperature may be associated to the release of heat from cocoa biomass during the fermentation process. Initially, the yeasts were dominant species that utilize the available fermentable substrate (such as sugar) before converting them into ethanol and further to acetic acid via microbial succession. The conversion of fermentable substrate into desired metabolite by-products was performed exothermically, and hence it assisted in the increase of temperature. The observed decline of the temperature during the 6th day of fermentation is one of the indicators that the fermentation process should be terminated as suggested by Khairul Bariah

et al (2014) in their study. If the temperature drops below 40°C from day 4 onwards, the cocoa should be immediately placed on the dryer, otherwise the cocoa will develop "off" flavors.

Table 3. Temperature (°C) of cocoa beans during fermentation as influenced by different quantities and durations of basket fermentation. Note that no data (Blanks in Table) were taken on some treatments after the duration of fermentation

Treatment	Initial	2nd Day	4th Day	6th Day
T_1	20.30	38.10	-	-
T_2	20.20	36.90	-	-
T_3	20.30	37.80	-	-
T_4	20.20	41.20	38.70	-
T_5	20.30	35.30	39.30	-
T_6	20.40	36.10	38.00	-
T_7	20.30	42.30	38.00	35.00
T_8	20.30	38.50	38.30	38.10
T_9	20.30	36.70	38.00	34.00
T_{10}	20.30	-	-	-

pH of Temperature (°C) Cocoa Bean After Fermentation

The pH and temperature of the cocoa beans were taken after the fermentation as shown in Table 4. For 3 days duration of fermentation the pH dropped to 3.77, 3.73 and 4.03 with 25kgs, 50kgs and 75kgs, respectively. The data showed that as the pH of the cocoa beans decreases, a corresponding increase of the temperature was observed. However, the trend noted for 5 and 7 days fermentation duration was that as the pH increases, the temperature decreased. According to Afoakwa et al (2014) the fermentation process produces alcohol and acids, and generates heat, typically raising the temperature of the fermenting beans within the first 72h. The acids lower the pH and cause acidification or souring of the bean which is a desirable quality in chocolate.

Table 4. pH and temperature of cocoa beans after fermentation as influenced by different quantities and durations of basket fermentation

Quantity	Duration					
	3 Days		5 Days		7 Days	
	pH	Temp. (℃)	pH	Temp. (℃)	pH	Temp. (℃)
25kgs	3.77	44.40	4.90	35.30	8.50	32.70
50kgs	3.73	41.70	5.10	41.30	5.70	37.30
75kgs	4.03	40.00	5.30	38.70	3.90	38.30

Bean Count

Bean count is defined as the total number of cocoa beans (excluding flat and broken beans) required to make a weight of 100g. Table 5 presents the data on the bean count revealing significant differences among treatments.

The conventional method (T_{10}) obtained the highest number of beans to make a weight of 100g. On the other hand, 3 days fermentation with 25kg, 5 days

fermentation with 25kg and 7 days fermentation with 75kg obtained the lowest bean counts at 91.40, 92.10 and 91.90, respectively. Data showed that unfermented beans seemed to have a lighter weight compared to the fermented beans. However, based on the Philippine National Standard, all treatments passed the standard for grade 1 on bean count (PNS/BAFPS: 58:2008). The death of the bean causes cell walls to break down and previously segregated substances to mix. This allows complex chemical changes to take place in the bean such as enzyme activity, oxidation and breakdown of proteins to amino acids. These chemical reactions cause the chocolate flavour and color to develop. Lastly, following fermentation the beans are dried and the oxidation reaction that begun through fermentation continues during drying (ICCO 2008). These fermentation processes contribute to the bean weight of fermented beans.

Table 5. Bean count of cocoa bean as influenced by different quantities and durations of basket fermentation

Treatment	Replication			Total	Mean**
	1	2	3		
T_1	92.30	85.70	96.20	274.20	91.40
T_2	96.80	90.90	93.80	281.50	93.80
T_3	96.20	98.40	95.20	289.80	96.60ab
T_4	90.90	92.30	93.20	276.40	92.10a
T_5	92.30	92.00	96.80	281.10	93.90ab
T_6	92.30	94.30	92.30	278.90	93.00ab
T_7	93.80	90.90	96.80	281.50	93.80ab
T_8	92.30	93.80	98.40	284.50	94.80ab
T_9	90.90	93.80	90.90	275.60	91.90a
T_{10}	100.00	100.00	100.00	300.00	100.00b
Total	937.80	932.10	953.60		
Mean	93.80	93.20	95.40		

CV = 3.53%
**Highly Significant at 1% level
Means having the same letter superscript are not significantly different with each other at 5% level of significance

pH and Titratable Acidity

Laboratory results are presented in Table 6. The level of acidity in cocoa beans is reflected by the pH value. It is the result of the diffusion of organic acids such as acetic, lactic, gluconic, oxalic, malic acid and propionic acid in cocoa beans during the fermentation process. According to Afoakwa (2014), cocoa beans of lower pH (4.75-5.19) and higher pH (5.5-5.8) were scored lower for chocolate flavour and higher for off-flavour notes, respectively, and chocolate from intermediate pH (5.20-5.49) beans scored more highly for chocolate. In this study, the 3 days fermenation with 25kg and 50kg; 5 days fermentation with 25kg and 50kg and 7 days fermentation with 50kg cocoa beans have obtained an intermediate pH. On the contrary, cocoa beans with lower acidity was produced with 75kg cocoa beans with whatever duration of fermentation. While 7 days fermentation with 25kgs obtained a higher pH which signifies a higher score for off-flavour notes. Results reveal a significant difference among the treatment means of titratable acidity. The highest titratable acidity was found in 3 days fermentation period with all quantities (25kgs, 50kgs and 75kgs) which ranged from 0.10 to 0.12.

Table 6. pH and titratable acidity (as acetic acid), % analysis of dried cocoa beans as influenced by different quantities and durations of basket fermentation

Treatment	Mean	
	pH*	Titratable Acidity** (as Acetic acid %
T_1	5.23^{ab}	0.11^{ab}
T_2	5.40^{ab}	0.12^{a}
T_3	5.00^{b}	0.10^{abc}
T_4	5.03^{b}	0.06^{cd}
T_5	5.33^{ab}	0.07^{abcd}
T_6	5.07^{ab}	0.05^{d}
T_7	5.63^{a}	0.06^{bcd}
T_8	5.23^{ab}	0.06^{bcd}
T_9	5.13^{ab}	0.08^{abcd}
T_{10}	5.30^{ab}	0.07^{abcd}
CV	3.85%	21.50%

*Significant at 5% level
**Highly Significant at 1% level
Means having the same letter superscript are not significantly different with each other at 5% level of significance

The result coincided with the findings of Guehi et al (2010) that titratable acidity was observed to peak at 3 days fermentation. Hii et al (2009) also explained that the highest volatile acidity in beans fermented for this duration is due to the accumulation of acetic acid which is mainly produced through oxidation of ethanol in the presence of oxygen by acetic acid bacteria. In addition, Ardhana and Fleet (2003) as mentioned by Apriyanto et al (2016) observed that the highest concentration of acetic acid in cocoa pulp occurred at 72h (3 days) fermentation and acidity levels decreased after 3 days fermentation. He further attributed this to be due to the majority of the acid produced have diffused into the beans. Biehl et al.(1982) as mentioned by Khairul Bariah (2014) stated that the diffusion of ethanol and acetic acid into the beans stimulates the onset of biochemical reactions leading to the development of chocolate color, flavor and aroma precursors.

Cocoa Beans' Grade

Based on the Philippine National Standard on Cacao or Cocoa Beans specification (Appendix A), the study found that there are five (5) treatments with a substandard grade as shown in Table 7 and Figure 1. These are treatments of 3 days duration with 25kg, 50k and 75kg; 5 days duration with 75kg and the conventional method. The 5 days duration with 25kg and 50kg and 7 days with 50kg attained a bean grade of 1A while 7 days duration with 25kg and 75kg obtained a grade 1B. Beans of grade 1A are superior and of good quality. These beans are of exportable quality and commands a much higher price compared to 1B and substandard beans. Generally, too short fermentation time had resulted to substandard cocoa beans while 5 days basket fermentation with 25kg and 50kg produced good quality cocoa beans. The 75kg for 5 days fermentation period obtained a large percentage of slaty beans and were graded as substandard cocoa beans.

Table 7. Cut test, bean count and bean grade for all cocoa beans as affected by different quantities and durations of basket fermentation

Treatment	Average Percentage							
	Fully Fermented	Under Fermented	Slaty	Mouldy	Defective	Over Fermented	Average Bean Count	Bean Grade
T_1	55.70	33.70	9.70	-	1.00	-	91.40	Substandard
T_2	47.00	36.30	16.00	0.30	0.30	-	93.80	Substandard
T_3	43.30	35.00	20.00	1.70	-	-	96.60	Substandard
T_4	87.00	9.30	3.00	0.30	0.30	-	92.10	1A
T_5	88.70	7.70	2.00	0.70	1.00	-	93.90	1A
T_6	64.00	19.30	16.00	0.30	0.30	-	93.00	Substandard
T_7	70.00	3.70	3.30	3.30	1.70	13.30	93.80	1B
T_8	81.30	2.00	3.00	1.00	1.00	11.70	94.80	1A
T_9	68.00	12.00	6.70	1.00	1.70	9.70	91.90	1B
T_{10}	-	21.70	64.70	0.30	0.70	-	100	Substandard

Sensory Quality

The quality of attributes of cocoa beans was determined from cut tests and sensory evaluation (Table 8). The visual assessment with the cut test provides information on the degree of fermentation, whereas flavor quality can be determined through sensory evaluation. Consumers generally dislike chocolate with excessive bitterness, astringency, sourness and other unacceptable off-flavors (Hii et al 2004). The best quality of dried beans is indicated by the degree of fermentation, low astringency and bitterness, and an absence of the off-flavors such as smoky notes and excessive acidity (Afoakwa et al 2012). The average rating scale of the sensory characteristics of cocoa liquor as influenced by different quantity and duration of basket fermentation is shown in Table 8. Based on the results, 7 days fermentation duration at 50kg obtained the highest acceptability rating on chocolate and bitterness at 5.10 and 4.80, respectively. This indicates that this duration and quantity have attained the chocolate and bitterness flavor attributes that are obvious/clearly noticeable. Results revealed a significant difference among the treatments on cocoa and bitterness flavor attributes. This shows that duration and quantity of basket fermentation plays a great role in developing positive flavor attributes.

The lowest rating for the chocolate flavor was obtained by the conventional method (T_{10}) and 5 days fermentation with 25kg produced the lowest rating for the bitterness. This suggests that the development of bitter and chocolate flavour attributes can be influenced by the quantity and duration of basket fermentation. The astringent score of the ten treatments ranges from 8.70 to 7.90. The highest astringency score was with the conventional method at 7.90. All of the samples for the ten treatments were moderately sour with scores ranging from 8.00 to 7.20. The sourness scores (moderately sour) were also observed by Khairul Bariah et al (2014). However, duration and quantity of basket fermentation had no significant contribution to the astringency and sourness of the fermented cacao beans. The result confirms the findings of Hii et al (2004) that there are no significant difference among the bean samples in terms of astringency and sourness as they were dried in the same manner.

In terms of aroma of the cocoa liquor, the panelists liked moderately the cocoa liquor from 5 and 7 days basket fermentation duration in all the studied quantities (25kg, 50kg and 75kg). Likewise, in terms of acceptability, 7 days duration with 25kgs of cocoa beans in basket fermentation received the highest rating of 9.80 which indicates that the panelist liked it very much.

Table 8. Sensory characteristics of cocoa liquor as influenced by different quantities and durations of basket fermentation.

Treatment	Mean				Aroma*	Acceptability*
	Bitterness**	Astringency^{ns}	Sourness^{ns}	Chocolate		
T_1	7.70^{ab}	8.80	8.00	7.40^{cd}	6.60	6.40
T_2	7.70^{ab}	7.10	8.60	7.70^{bcd}	6.70	7.80
T_3	7.60^{ab}	8.70	8.70	7.90^{bcd}	6.40	6.10
T_4	8.80^{b}	7.10	7.20	7.60^{bcd}	7.90	6.40
T_5	7.60^{ab}	7.00	7.70	6.40^{abc}	7.80	7.60
T_6	6.00^{ab}	7.10	7.20	6.20^{abc}	7.80	7.30
T_7	6.50^{a}	7.20	7.20	6.50^{ab}	7.80	9.80
T_8	6.80^{a}	7.40	7.30	5.10^{a}	7.30	8.70
T_9	7.60^{ab}	8.80	8.10	6.60^{ab}	7.00	8.90
T_{10}	7.80^{ab}	7.90	7.70	7.00^{d}	6.80	4.20

ns= not significantly different at 5%
** = highly significant at 1% level
Means having the same letter superscript are not significantly different with each other at 5% level
*Hedonic Scale 1 - Dislike Extremely; 2 - Dislike Very Much; 3 - Dislike Moderately; 4 - Dislike Slightly; 5 - Neither Like nor Dislike; 6 - Like Slightly; 7 - Like Moderately; 8 - Like Very Much; 91 - Like Extremely

Cost and Return Analysis

The cost and return analysis per treatment is shown in Table 9. Production cost includes materials and labor cost. Materials include cocoa beans, baskets, plastic sacks, net and bamboos while the labor cost includes the cost of hauling the beans, loading of beans into plastic baskets, weighing andloading of beans into baskets, collection of banana leaves, turning the beans, sun drying the beans and sorting. The 5 days fermentation with 50kg obtained a production cost of PHP41.85 and net income of PHP15.70 kg^{-1} of cacao beans which gave the highest return on investment (ROI) of 37.5%. The superior quality of 5 days fermentation with 50kg with a grading of 1A and a higher selling price at PHP160 kg^{-1} of dried cocoa beans are factors for its high ROI.

On the other hand, the conventional method had attained the lowest return on investment (ROI) at 0.79% only. It has the selling price of only PHP120 kg^{-1} due to its substandard quality. The higher cost of wet beans and the additional cost of drying are the factors of a very low ROI obtained by the conventional method. At an average of 800kg dried cocoa beans yield per hectare, a farmer can have an additional income of PHP12,500 if he adopts 5 days duration of basket fermentation.

The 5 days fermentation with 50kg and 7 days fermentation with 25kg (T_4 and T_7) had the highest production cost per kilogram of beans at PHP42.50 while the conventional method (T_{10}) had the lowest production cost per kilogram at PHP40.45. The study showed that 5 days fermentation with 50kgs (T_5) has the highest net income per kilogram of beans at PHP15.70 while the llowest is the conventional method (T_{10}) at PHP0.32.

Table 9. Cost and return analysis of cocoa beans at different quantities and durations of basket fermentation

Treatment	Production Cost, Php		Total Production Cost, Php (c = a+b)	Production Cost/kg, Php	Production Dried Cocoa Beans (kgs)	Gross Income, Php (d)	Net Income, Php (e = d-c)	Net Income /kg. Php	ROI(%)	*Net Income, Php
	Material (a)	Labor (b)								
T_1	2,947.25	221.50	3,168.75	42.25	27.00[c]	3,240.00	71.25	0.95	2.20	760.00
T_2	5,797.25	442.00	6,239.25	41.60	53.00[c]	6,360.00	120.75	0.80	1.90	640.00
T_3	8,647.25	662.50	9,309.75	41.35	79.00[c]	9,480.00	170.25	0.75	1.80	600.00
T_4	2,947.25	240.50	3,187.75	42.50	26.00[a]	4,160.00	927.25	13.00	30.60	10,400 0.00
T_5	5,797.25	482.00	6,279.25	41.85	54.00[a]	8,640.00	2,360.75	15.70	37.50	12,560. 00
T_6	8,647.25	723.50	9,370.75	41.65	81.00[c]	9.720.00	349,25	1,.55	3.70	1,240
T_7	2,947.25	240.50	3,187.75	42.50	25.50[b]	3,468.00	280.25	3.70	8.70	2,960.0 0
T_8	5,797.25	521.00	6,318.25	42.10	52.00[a]	8,320.00	2,001.75	13.30	31.60	10,640. 00
T_9	8,647.25	784.50	9,431.75	41.90	83.00[b]	11,288.0 0	1,856.25	8.25	19.70	6,600.0 0
T_{10}	5,766.00	405.50	6,031.50	40.45	51.00[c]	6,120.00	48.50	0.32	0.79	256.00

Fermented Beans Price kg^{-1} (PHP): [a]1A beans=160.00; [b]1B=136.00 and [c]Substandard=120.00 *Estimated Average Yield of dried cocoa beans @ 800kg ha^{-1}

CONCLUSION AND RECOMMENDATION

The results of the study revealed significant differences on the quality of cacao beans in terms of percentage of fully fermented beans, under fermented beans, slaty beans, moldy beans, defective beans, pH and titratable acidity of the dried cocoa beans. In addition, an important flavour attribute is dependent on the duration and quantity of basket fermentation as the study showed significant results on the sensory quality of the chocolate and bitterness flavour attributes. However, this study found that no significant differences were revealed on the sourness and astringency of the cocoa liquor with the quantity and duration of basket fermentation.

Fermentation duration of 5 days with 25kg and 50kg of cocoa beans and 7 days duration with 50kg of cocoa beans attained grade 1A, a good quality based on the Philippine National Standard for cacao bean grading. The majority of the beans fermented for 3 and 7 days were of lower quality as revealed in the cocoa bean grading. The pH and titratable acidity of the dried cacao beans were influenced by the duration and quantity in basket fermentation. Chocolate and bitterness flavour attributes were also influenced by the duration and quantity with basket fermentation. However, astringency and sourness were not influenced by the duration and quantity of basket fermentation. Five days of fermentation period with 50kg had the highest return compared to other treatments used in this study. The best fermentation duration and quantity based on the results and findings of this study are 5 days duration with 25kg and 50kg in each 520x325x280mm bamboo basket. Basket fermentation can be used and should be encouraged as an improved fermentation method for small and backyard cacao growers who cannot afford to construct a fermentation facility using boxes.

Based on the results and analysis of the study, it is recommended that basket fermentation with 25kg and 50kg of cocoa beans with 5 days duration can be used to obtain good quality fermented beans. It is likewise, recommended, to conduct further studies on the use of basket fermentation during the period of low cacao harvest in April and May to validate the findings and results of this research.

REFERENCES

Afoakwa EO, Quao J, Akomanyi E, Takrama J, Budu AS & Firibu SK. 2012. Changes in total polyphenols, o-diphenols and anthocyanin concentrations during fermentation of pulp pre-conditioned cocoa (*Theobroma cacao*) beans. *International Food Research Journal* 19(3):1071-1077

Afoakwa EO, Budu AS, Mensah-Brown H & Felix J. 2014. Changes in biochemical and physico-chemical qualities during drying of pulp preconditioned and fermented cocoa (*Theobroma cacao*) beans. *Journal of Nutritional Health and Food Science* 2(1):1-8

Afoakwa EO, Quao J, Budu AS, Takrama J & Firibu KS. 2011. 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* 62(7): 755-764

Emmanuel OA, Jennifer Q, Agnes SB, Jemmy ST & Firibu KS. 2012. Influence of pulp-preconditioning and fermentation on fermentative quality and appearance of

Ghanaian cocoa (Theobroma cacao) beans. *International Food Research Journal* 19(1):127-133

Huynh XP, Thanh NV & Toan HT. 2009. Cocoa processing and fermentation for production of high-quality cocoa in Vietnam. Proceedings from the 3rd International Conference on Fermentation Technology for Value Added Agricultural Products (FerVAAP), Can Tho City, Vietnam. Biotechnology Research and Development Institute, Can Tho University

Apriyanto M. 2016. Study on effect of fermentation to the quality parameter of cocoa bean in Indonesia. Asian Journal Dairy & Food Research 35(2): 160-163

Ardhana MM and Fleet GH. 2003. The microbial ecology of cocoa bean fermentations in Indonesia. International Journal of Food Microbiology 86(1-2): 87-99

Biehl B. 1986. Cocoa fermentation and problem of acidity, over-fermentation and low cocoa flavour. Incorporated Society of Planters, Kuala Lampur, Malaysia

Biehl B, Passern D & Sagemann W. 1982. Effect of acetic acid on subcellular structures of cocoa bean cotyledons. *Journal of the Science of Food and Agriculture* 33(11): 1101-1109

Espino RRC and Ramos JV. 2008. Cacao Technology Resource Manual. Department of Agriculture, Ginintuang Masaganang Ani (GMA), High Value Commercial Crops (HVCC), Program and Cocoa Foundation of the Philippines, Inc. (CocoaPhil). Quezon City, Philippines

Guehi TS, Dadie AT, Koffi KP, Dabonne S, Ban-Koffi L, Kedjebo KD & Nemlin GJ. 2010. Performance of different fermentation methods and the effect of their duration on the quality of raw cocoa beans. *International journal of food science & technology* 45(12): 2508-2514

Guehi TS, Zahouli IB, Ban-Koffi L, Fae MA & Nemlin JG. 2010. Performance of different drying methods and their effects on the chemical quality attributes of raw cocoa material. *International Journal of Food Science & Technology* 45(8):1564-1571

Guehi TS, Koffi KPB & Dabonne S. 2010. Spontaneous cocoa bean heap fermentation: Influence of the duration and turning on the quality of raw cocoa. *World Academy of Science, Engineering and Technology* 70:118-123

Hii CL, Samuel YKC & Haslita IN. 2004. Quality assessment of cocoa beans produced by smallholders from different regions in Malaysia. *Malaysian Cocoa Journal* 1:53-58

Hii CL, Law CL, Cloke M & Suzannah S. 2009. Thin layer drying kinetics of cocoa and dried product quality. *Biosystems engineering* 102(2):153-161

Cocoaskiss.blogspot.com. 2016. How does the fermentation process work on the cocoa bean and how long does it take?. Accessed from https://cocoakiss.blogspot.com/2016/11/how-does-fermentation-process-work-on.html

Kongor JE, Takrama JF, Budu AS, Mensah-Brown H, Afoakwa EO. 2013. Effect of fermentation and drying on the fermentation index and cut test of pulp preconditioned Ghanaian Cocoa (*Theobroma cacao*) beans. *Journal of Food Science and Engineering* 3:625-634

Sulaiman KB, Ibrahim WAW & Yang TA. 2014. Effect of fermentation duration using shallow box on Ph, equivalent percent fully brown and flavour attributes of Malaysian Cocoa Beans. *Journal of Applied Science and Agriculture* 9(11):104-108

Khairul BS. 2014. Impact of fermentation duration on the quality of Malaysian cocoa beans using shallow box. *Asia-Pacific Journal of Science and Technology* 19: 74-80

Khairul BS and Board MC. 2006. Effect of fermentation cover on the quality of Malaysian cocoa beans-a preliminary study. *Proceedings from the Malaysian International Cocoa Conference*, Sunway Pyramid Convention Centre, Kuala Lumpur, Malaysia), 18-19 Jul 2005. Malaysian Cocoa Board

Magallon WN, Patalinghug ME & Tangalin MG. 2022. Status of Cacao (Theobroma cacao L.) production on its challenges and prospects in Zamboanga del Norte Province in the Philippines. International Journal of Agricultural Technology 18(3):1075-1092

Malaysian Standard 293. 2005. Cocoa Beans – Specification for Grading (4th Revision). Department of Standard Malaysia, Federal Government Administrative Center, Putrajaya, Malaysia

Mikkelsen L. 2010. Quality assurance along the primary processing chain of cocoa beans from harvesting to export in Ghana. Student in Food Science at the University of Copenhagen, Faculty of Life Sciences, Frederiksberg

Vázquez-Ovando A, Chacón-Martínez L, Betancur-Ancona D, Escalona-Buendía H & Salvador-Figueroa M. 2015. Sensory descriptors of cocoa beans from cultivated trees of Soconusco, Chiapas, Mexico. *Food Science and Technology* 35: 285-290

Philippine National Standard for Cacao or Cocoa Beans (PNS/BAFPS 58:2008)

Reed S. 2010. Sensory Analysis of Chocolate Liquor: Sophisticated sciences such as sensory and flavor chemistry are needed to understand flavor development. The Manufacturing Confectioners. Retrieved from https://www.worldcocoa foundation.org/wp-content/uploads/files_mf/reed2010.pdf

Said M, Meyer B & Biehl B. 1988. Pulp preconditioning – A new approach towards quality improvement of Malaysian Cocoa Beans (pp28-57). *Proceedings of MARDI Senior Staff Conference*, Kuala Lumpur, Malaysia

Schwan RF and Wheals AE. 2004. The microbiology of cocoa fermentation and its role in chocolate quality. *Critical Reviews in Food Science and Nutrition* 44(4): 205-221

Shamsuddin S, Idrus AZ & Hassan MH. 1978. Preliminary efforts to improve the quality of cocoa beans. *Proceedings from the International Conference on Cocoa and Coconuts: Progress and Outlook*. The Incorporated Society of Planters, Kuala Lumpur, Malaysia

Wood GAR and Lass RA. 2001. Cocoa (4th edn). Blackwell Science, Oxford