INFLUENCE OF POST HARVEST PROCESS, GENOTYPE AND ENVIRONMENTAL FACTORS ON SELECTED COCOA QUALITY ATTRIBUTES

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ABSTRACT

The cocoa bean quality attributes are influenced by genotype, environmental factors, and plant size. The fat content of the bean is influenced by pod ripeness and affected by pod storage period. The clonal material produce desirable physical quality parameters; however there is negative correlation

Key words: *Post harvest process, quality parameters, genotype and environmental factors*

INTRODUCTION

Fat is an important quality attributes that decides in most case, the end price of cocoa. The standard fat content most manufacturers prefer is greater than 56 %; expressed in dry weight basis. Fat content of the beans increases during pod development. Fully ripe pods usually have maximum fat level as compared to unripe and partially ripe pods. Fat is lost if pods are not harvest on time. Overripe pods can lose fat through germination. Fat loss during fermentation is not significant as shown by work carried out by Roelofsen (1959); Forsyth and Quesnel (1963). Also, chemicals studies of germination showed that decrease in fat, starch and protein occur in the cotyledon over period of several days. When germination occurs, it reduces the value of cocoa by reducing the fat content and opens the testa.

That fat content varies between different genotypes, and is influenced by environmental factors. The fat content of the cocoa beans is determined by the genetic composition of the plant .The influence of genotype was demonstrated by Forastero genotypes, with a fat content between 56-58 %, in contrast to some Amazonian crosses from Ghana and Ivory Coast with a fat content range between 58-61 % . Criollo beans have a low fat content around 53 % (Wood, 1975). It appears that there is no genetic correlation between cocoa butter content and yield or bean weight (Lockwood and Pang, 1995), but there is a correlation between bean weight and cocoa butter within the clones (Beek *et al.*, 1977). The genetic effect on cocoa butter hardness is small compared to the environment factors (Lockwood and Eskes, 1995). Low fat content was associated with beans developing during the dry season. However, results of some studies proposed that, in addition to rainfall, temperature could influence the fat content. Some of the variation in cocoa butter content may also be due to xenia effects. Ehrencron and Heemskerk (1976) found that change of pollen parent could alter cocoa butter content by up to 4.8 %; a similar, but smaller effect was reported by (Beek *et al.*, 1977).

Bean weight is the average weight of one bean and bean count is the total weight of 100 beans. The standard bean weight preferred by most manufacturers is between 0.8-1.0 g/bean. Bean weight is negatively correlated with shell content. The average bean weight is determined by environment, but the there is no evidence of interaction between season and genotype (Lockwood and Edward, 1980). Tan, (1990) have shown high heritability of bean weight, an additive component of genotype variance and absences of material effects.

The shell content of bean varies depending on genotypes, and negatively correlated with bean weight (Vello *et al.*, 1972). The shell content of the beans was significantly influenced by month and genotype. The shell content is also significantly influenced by plant size (Kuman *et al.*, 2005a). The shell content of the bean could be genetically controlled.

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Recovery rate is the ration of dry fermented beans to wet unfermented beans expressed as a percentage. Recovery rate can be influenced by season, genotype or method of processing. Pod storage prior to fermentation increased the recovery rate (Kuman, 1998). Howat *et al.*, (1957) reported the influence of cocoa genotype on recovery rate (i.e. Amelonado 44 % and Amazon 38 %). The recovery rate varies considerably from 30 % to well over 40 % (Kuman, 1998). Ronan (1963) published data on recovery rates varying from 31.5 % in Ecuador to 46 % from Zaire. Season is another major factor affecting the recovery rate. Recovery rate rises during the dry season, and fall in the wet season (Wood, 1975). Are and Atanda (1972) reported a 46.3 % recovery rate in the dry season and 38 % in the wet season. Pod ripeness also influences recovery rate; recovery rate increases as the pods ripens (MacLean and Wickens, 1951).

OBJECTIVE

The objective of this study is to assess the influence of post harvest process, pod ripeness and environmental factors on bean quality attributes.

MATERIAL AND METHODS

Location

The quality data of genotype (Kuman, 2005) were collected from a breeding trial conducted at the Papua New Guinea Cocoa and Coconut Research Institute, Tavilo Rabal; East New Britain. The environmental condition of the trial site was reported in cocoa breeding report in the Papua New Guinea Cocoa and Coconut Research Institute (1998) Annual Report. The average rainfall of 134.9 mm with a maximum of 343.9 mm and minimum (12.5 mm) was recorded during the 24 months when this trial was conducted. The clonal material assessed were the progenies of original Trinitario and Amazonian parents (Kuman, 2005).

Experimental Design

The breeding trial was divided into three sub trials based on the three size: small trees (1-1.5 m), intermediate (1.5-3 m) and large (>5 m). The trees of each class were of the same age uniform in each replicate and were planted in split-plot design. Four replicates were used with 12 trees in a (3 m x 3 m) plot.

Effect of harvest and pod storage

The effective harvest and pod storage experiement was conducted to assess the effect of harvest interval pod storage on fat content. A factorial experimental design was set up with harvest intervals of 1, 2 and 3 weeks combined with pod storage time of 0, 5 and 10 days as shown in Table 1. The experiment was conducted for a period of 6 months.

Table 1: Effect of harvest intervals and pod storage on fat content

Treatment	PSO	PS5	PS10
HI Week	Ti	T2	T3
HI Week	T4	T5	T6
HI Week	T7	T8	T9

Key:
HI=Harvest Interval
PS=Pod storage
T= Treatment

Data collection

a) Quality analysis

Ripe pods of approximately 1 kg (equivalent to 6 pods) were harvested twice every month from each of the genotype. The pods were transported to the laboratory and their husks were removed. The wet beans of approximately 1 kg were collected from each genotype, labeled, wrapped inside the shade cloth bags and fermented using a procedure described by Clapperton *et al.*, (1994).The beans were dried at the end of 6 days fermentation and their quality attributes (shell content, fat content, bean size including recovery rate) were determined over a period of 12 months.

b) Effect of harvest and pod storage

Wet beans collected from each treatment (Table 1) were micro-fermented (Kuman, *et al.*, 2010), dried and their fat content was analyzed. The beans processed using fermentation methods described by Clapperton *et al.*, (1994) and Kuman *et al.*, (2010) produce same quality attributes. The two fermentation methods were used alternative to generate samples for quality assessment.

Sample collection and Preparation

Approximately 600 g of dried beans from each genotype was dried inside the oven (Contherm, New Zealand). At 115 °C for 15 min to standardize moisture content to less than 7 % before being emptied into a mixing container, and thoroughly mixed. Any foreign materials and debris were removed before passing the samples into a funnel of a quartering, which randomly divided the sample into four quarters. Approximately, 150 g of beans received from each quartering devise was used to analyze the bean size, fat content and shell content.

Sample Analysis

Fat content of the beans was extracted using the standard fat extraction method (AOAC, 1970). The other quality attributes (bean size, shell content, recovery rate) were determined using the standard cocoa quality analysis procedure described by Kuman *et al.*, (2001).

Data Analysis

Quality data were subjected to analysis of variance to determine the influence on bean quality attributes and reported (Kuman *et al.*, 2005a).

RESULTS

There was a significant amount of fat loss recorded during pod storage and harvest intervals. There was no economical benefit in prolonged pod storage beyond two days, as the pods were shown to be heavily infected by fungus resulting in heavy loss of pods (75-80 % loss to fungus infection).

Pods harvested at week 2, has the maximum average fat content of 58.3 %, an increase of 1 % fat. This is when fully matured pods were harvested and fermented. Large amount of fat (1 % on average) was lost between week 2 and 3, which coincided to an increase in bean germination from week 2 to week 5 (Figure 1) as the result of harvesting overripe pods.

Table 2: Effect of harvest interval and pod storage on fat content

Treatment	PSO	PS5	PS10	Mean
HI Week 1	57.69 (± 0.2)	56.95 (± 0.3)*	56.36 (± 0.2)**	57.0
HI Week 2	58.54 (± 0.2)	58.46 (± 0.4)*	58.03 (± 0.3)**	58.3
HI Week 3	57.51 (± 0.2)	56.78 (± 0.2)*	56.18 (± 0.1)**	56.8
Mean	58.2	57.4	56.9	

Key: HI=Harvest PS=Pod storage T= Treatment
*P≤ 0.05 **P≤ 0.01 *** P≤ 0.001 (NS) Not significant

Figure 1: Effect of harvest interval on fat content

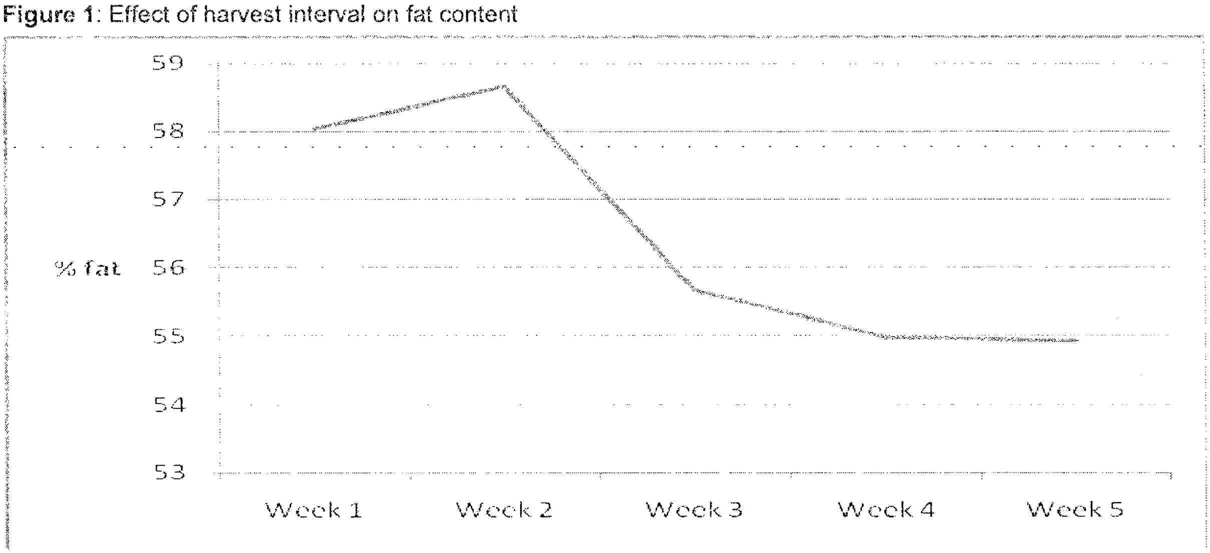
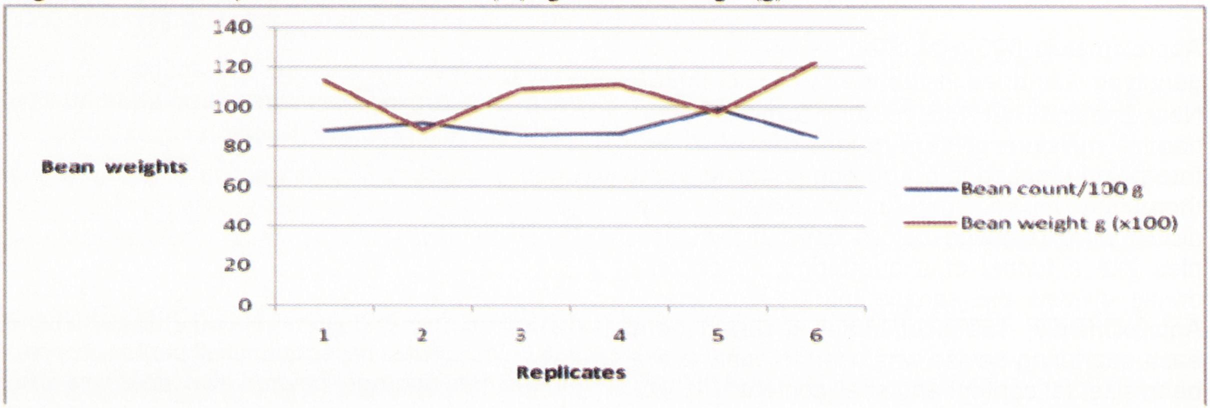


Figure 2: Relationship between bean counts (%) against bean weight (g)



The bean count is expressed in percentage (weight of 100 beans) and average bean weight (average weight of single bean) expressed in percentage as shown in the figure 2 to illustrate the relationship between the two attributes. There is a negative correlation between bean count and bean weight. The lower the bean count, the bigger the bean or vice versa.

Table 3: Effect of pod storage on recovery rate

Clone	Recovery rate	
	Beans fermented straight after harvest	Bean fermented after two days of pods storage
38-3/4	39.5	46.3
38-8/2	32.7	42.5
33-15/1	29.2	42.5
34-13/2	31.3	46.5
23-3/1	32.5	40.5
KA2-101	30.0	43.4
16-2/3	38.7	45.0
67-9/3	31.3	43.6
23-6/1	32.5	44.4
67-9/3	35.0	40.3
23-6/1	32.5	40.5
Mean	33.2	43.2
Range	29-39.5	40-46.5
Std	3.3	2.2

**Minibox fermentation method described by Kuman et al., (2009)*

The average recovery rate was 33.2 %, and range from 29-39.5 % for pods not stored. Pods stored two days before fermentation yield higher recovery rate (average increase of 10 %) than beans fermented straight after harvest. Similar results were obtained for commercially fermented beans.

Table 4: Assessment of individual quality attributes of the hybrid clones-Recovery rate

a) Plant density: Big plants

Clone	16-3/2	16-2/3	73-2/2	38-8/2	K82	38-3/4	34-14/4	36-3/1	37-13/3	36-8/3	KA2-101	37-13/1
Range	27-32.1	28-33.6	28.5-32	28.5-31.7	31-39.3	32-36.8	29-34.2	26-31.7	26-34.1	30-32.7	21-32.9	26.2-31.3
Mean	30	30	30	30	35	34	33	29	30	32	28	29
Std	2	2	2	2	2	2	2	2	3	1	3	2

b) Plant density: Intermediate plants

Clone	67-9/3	25-6/3	73-6/1	73-3/3	17-14/4	33-8/3	23-3/1	37-6/4	33-15/1	38-10/3
Range	26-30.4	31-36.8	29-36.4	31-37.3	29-33	29-32.6	28-32.8	30-34.8	25-29.1	26-32.2
Mean	29	33	34	33	32	32	32	32	31	30
Std	1	2	2	2	1	1	1	2	2	2

c) **Plant density:** Small plants

Clone	24-4/1	17-3/1	24-9/1	23-6/1	17-7/4	34-13/2	73-14/1	24-7/1	63-7/3
Range	28-32.6	27-32.6	26.6-30.3	23-28.9	30-34.1	21-27.3	30-31.9	30-32.6	25-29.6
Mean	30	29	29	26	32	25	31	32	27
Std	1	2	2	2	1	2	1	1	2

The quality attributes of individual clones are presented in Table 4, 5, 6 & 7 to assess the relationship between each bean quality attributes, its influence by the environmental factors and plant size (density).

The recovery rate of the clones varies with an average of 30.6 %, range from 21-39.4 %. The recovery rate was shown to be influenced by genotype and month, but not tree size (Kuman, 2005*a).*

Table 5: Quality attributes of the hybrid clones-Shell content

A. Plant density: Big

Clone	16-3/2	16-2/3	73-2/2	38-8/2	K82	38-3/4	34-14/4	36-3/1	36-8/3	KA2-101	37-13/3	37-13/1	34-14/4
Range	14-17.4	16-18.2	15-18.5	13-15.7	15-18.8	14-17.7	13-16.2	15-18.8	14-14.8	14-17.4	15-18.6	14-16.4	13-`16.2
Mean	16.1	17.4	17.0	14.6	17.3	16.4	14.8	17.1	14.0	15.8	15.3	15.3	14.8
Std	1	1	1	1	1	1	1	1	1	1	1	1	1

B. Plant density: Intermediate

Clone	67-9/3	25-6/3	73-6/1	73-3/3	17-14/4	33-8/3	23-3/1	37-6/4	33-15/1	38-10/3
Range	16-18.9	12-16.2	15-17.5	15-18.8	14-16.5	14-17.5	15-17.6	15-18.1	15-16.5	14-16.6
Mean	17.9	14.7	16.2	17.5	15.4	16.1	16.6	17.1	15.5	16.0
Std	1	1	1	1	1	1	1	1	1	1

Plant density: Small

Clone	24-4/1	17-3/1	24-9/1	23-6/1	17-7/4	34-13/2	73-14/1	24-7/1	63-7/3
Range	14-16.6	15-17.7	17-18.0	5-17.2	6-18.0	5-17.8	16-18.7	17-15.6	15-18.8
Mean	15.8	16.4	17.8	16.4	16.9	16.6	17.4	14.9	17.7
Std	1	1	1	1	1	1	1	1	1

The shell content of the clones varies with an average of 15.5 %; range from 14-17.9 % .The shell content of the beans size was shown to be influenced by month, genotype and tree size.

Table 6: Quality attributes of the hybrid clones-Bean size

Plant density: Big

Clone	16-3/2	16-2/3	73-2/2	38-8/2	K82	38-3/4	34-14/4	36-3/1	36-8/3	KA2-101	37-13/3	37-13/1	34-14/4
Range	1.0-2.1	1.2-1.5	1.0-1.59	1.0-1.8	0.92-1.2	1.3-1.7	1.4-1.8	1.2-1.7	1.3-1.6	1-1.5	1.0-2.0	1-1.2	1.2-1.7
Mean	1.7	1.4	1.5	1.6	1.1	1.5	1.5	1.6	1.5	1.4	1.6	1.1	1.5
Std	0.3	0.2	0.1	0.2	0.3	0.1	0.1	0.4	0.1	0.1	0.1	0.1	0.2

Plant density: Intermediate

Clone	67-9/3	25-6/3	73-6/1	73-3/3	17-14/4	33-8/3	23-3/1	37-6/4	33-15/1	38-10/3
Range	1.2-1.5	1.3-1.6	1-.3-1.7	1.6-2.0	0.8-1.3	1.1-1.4	1-1.3	1.05-1.5	1.1-1.3	1.0-1.8
Mean	1.3	1.3	1.3	1.4	1.2	1.2	1.2	1.3	1.2	1.6
Std	0.5	0.4	0.2	0.5	0.1	0.2	0.1	0.2	0.1	0.2

Plant density: Small

Clone	24-4/1	17-3/1	24-9/1	23-6/1	17-7/4	34-13/2	73-14/1	24-7/1	63-7/3
Range	1.3-1.5	0.8-1.1	1.1-1.2	0.8-1.0	1.0-1.2	0.9-1.4	0.8-1.2	1.1-1.2	0.9-1.8
Mean	1.2	1	1.1	0.9	1.1	1.2	1.1	1.1	1.3
Std	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3

The bean weight of the clones varies with an average of 1.3 g, range from 0.9-1.7 g. The bean weight was shown to be influenced by genotype and plant size, with no effect of monthly environmental factors.

Table 7: Quality attributes of the hybrid clones-Fat content

Plant density: Big

Clone	16-3/2	16-2/3	73-2/2	38-8/2	K82	38-3/4	34-14/4	36-3/1	36-8/3	KA2-101	37-13/3	37-13/1	34-14/4	Across Clone Mean
Range	55-59.3	56.8-59.7	58-59.7	48.8-52.2	56.5-57	52.3-53.4	54.1-56.1	54.9-55.4	57.2-59	52.4-54.8	54.5-58.6	56.4-57.7	52.5-56.1	
Mean	57	58	58	50	57	53	54	55	58	54	58	57	54	55.6
Std	2	1	1	2	1	1	1	1	1	1	1	1	1	

Plant density: Intermediate

Clone	67-9/3	25-6/3	73-6/1	73-3/3	17-14/4	33-8/3	23-3/1	37-6/4	33-15/1	38-10/3	Across Clone Mean
Range	55.1-58.9	56.2-57.1	59.3-60.6	55.5-58.7	58.2-58.6	53.1-53.9	54-55.8	56.8-58.9	57.3-59.2	56.5-59	
Mean	57	57	60	57	59	53	54	58	58	57	57
Std	2	1	1	1	1	1	1	1	1	1	

Plant density: Small

Clone	24-4/1	17-3/1	24-9/1	23-6/1	17-7/4	34-13/2	73-14/1	24-7/1	63-7/3	Across Clone Mean
Range	55.2-55.5	60.1-60.6	51.6-55.7	55.4-57	57-58.6	54.1-53.9	54.4-55.7	56.5-58.5	58.2-59.1	
Mean	55	60	54	56	58	54	55	58	58	56.4
Std	1	1	1	1	1	1	1	1	1	

The fat content of the clones varies with an average of 56.3 %, and range from 53-60 % on dry weight basis. The fat content was shown to be influenced by genotype and environment variations but not tree size (Kuman, 2005*a)*

DISCUSSION AND CONCLUSION

Pod harvest & storage

Pod harvest can be delayed up to a maximum period of two weeks. Pods can be left on the tree, until they are fully ripped before harvesting, and this is when the maximum fat content of the beans is reached (Figure 1). When pod harvest is delay beyond two weeks, the beans started to loss significant amount of fat as the result of seed germination; seeds used food reserve (fat) to germinate.

There is no economical benefit to harvest, and store pods beyond 2 days as they were shown to be infested with fungus, resulting high pod loss. Pods though, can be harvested and stored up to a maximum of 2 days in order to increase the recovery rate. Higher average recovery rate of 40 % was achieved for beans from storage pods compared to 30 % for beans fermented straight after harvest; an increase of 10 % recovery rate.

Fat content

Fat content of the beans is influenced by genotype and genotype x environment (G x E) interaction. Fat content contributed 28 % to the total sum of squares (SS). The plant size does not affect the fat content (Kuman *et al.*, 2005a). The results in (Table 7) indicated that fat content is not influenced by bean weight and shell content. For example, clone 16-2/3 has an average bean weight of 1.4 g and shell content of 17.4 %, but has a high fat content of 58.0 %. Contrary, clone 34-14/4 has the average bean weight of 1.5 g and shell content of 14.8 %, but has a low fat content of 54.0 %. This means, clones with large bean size and low shell content does not necessary produce high fat content. Pearson correlation coefficient indicated that there is no association between any of the quality parameters, except between recovery rate and the fat content (Kuman, 2009).

Shell content

The shell content of the bean was significantly influenced by monthly environment variation and genotype. Genotype contributed (25 %) to the total SS followed by month (3 %) (Kuman *et al.*, 2005a). The average shell content of the clones was 15.5 %, and range from 14-17.9 %. The shell content of the beans does not influence the fat content or the bean weight. Beans with high shell content still have large bean weight containing high fat content. The shell content of the bean could be genetically controlled. Moretzsohn *et al.*, (1999) showed that shell thickness of the seed was likely to be controlled by a single locus with two alleles (sh^+ and sh^-) showing co-dominant expression. There is no economical value to identify clones with low shell content as low as 13-14 %, which has been the focused of research in the past. Similarly, there is no need to make further effort or adopt post harvest methods to reduce shell content as there are no economical benefits; this can only incur additional overhead cost to the farmers.

Bean weight

The bean weight of the clones varies with an average of 1.3 g and range from 0.9-1.7 g. All the genotypes produce large bean weight greater than the normal required bean weight of 0.9-1 g. The weight is influenced by genotype and less affected by monthly environmental variation and tree size. Genotype contributed largest percentage of sum of square (35 %) to the total SS (Kuman *et al.*, 2005a). There is no positive correlation between bean weight, shell and fat content. A large bean does not necessarily have high fat content, and low shell content. For instant, clone 36-3/1 (Table 5,6 & 7) has an average bean weight of 1.6 g, but has high shell content of 17.1 % and low fat content of 55 %, while clone 38-10/3 has smaller bean weight of 1.3 g, with reasonably high shell content of 16 .0 %, but still produce high fat content of 57.0 %.

Recovery rate

Recovery rate is significantly influenced by monthly environment variation and genotype. Genotype contributed (22 %) to the total SS followed by month (3 %). The recovery was not influenced by the tree size (Kuman *et al.*, 2005a). The mean recovery rate was 30.6 % with a range from 21-39 %. Some clones that shown to have high recovery rates above 30 % (Table 3 & 4). The recovery rate is also influenced by post harvest process; beans from stored pods yield high average recovery rate of 43.4 % compared to 33.2 % for bean fermented straight after harvest (Table 3 & 4). The possible reason for difference observed in the recovery rate could be related to the bean composition. Beans that developed during wet season have large pulp volume to bean ratio, and would normally have a lower recovery rate than beans produced in the dry season (Wood and Lass, 1985). The increase in the recovery rate of beans as the result of pod storage could be the results of increase in fat due to pod ripeness as demonstrated in figure 1.This also confirms the strong correlation exist between recovery rate and fat content.

CONCLUSION

The selection of the clones for breeding and distribution to the farmers obviously has to be based on what the manufactures prefers. The manufacturers prefer bean quality attributes based on their specific quality requirements and operational specification. The quality requirements may vary between manufacturers, but fall with the following acceptable standards. The manufacturers prefer bean fat content above 56 %, shell content between 11-12 % (beans offering a large edible proportion and less waste). The shell content of the beans have to be as low as possible, but of adequate thickness to protect the beans from mould and insect invasion. However, thick shell content is also valuable as it protects the beans from cracking during storage and handling. The bean weight prefers by most manufacturers is between 0.8-1.0 g/bean. The selection of the ideal clones has to be based on the combination of the quality attributes preferred by the manufacturers.
Pod harvest can be delayed for two weeks to allow fat content in the beans to reach its maximum level before harvest. This practice is economical viable and convenient to smallholder farmers, who need time to collect sufficient pods for fermentation. There is a risk of significant pod loss, if pods are harvested and stored beyond two days; prolonged storage pods was shown to be heavily infected by fungus.

The recovery rate is another value adding attribute that needs to be included in selection of the clones, as it is an in direct measure of yield. An increase in recovery rate is an economical gain. The high recovery rate is also an indication of beans containing fat content as there is a strong correlation between recovery rate and fat content.

In this study, it shows that nearly all the clones have large average beans weigh around 1 g / bean. Most of the clones produce high fat content above 56 %, while few containing higher fat content from 59-60 %. The shell content of the beans is high, well above the standard (11-12 %) preferred by the manufacturers. However, this should not be a concern because manufacturers prefers large edible portion of the beans, which the clones can produce in the form of high fat content and large bean weight. The results from this study indicated that there is no correlation between each of these qualities attributes, therefore beans with high shell content can still produce high fat content and large bean weight to meet the requirements of the manufacturers.

FUTURE RESEARCH

The future quality research needs to be focused on breeding and distribution of clones with high fat content and large bean size. The shell content becomes secondary importance. The important quality parameters (fat and bean size), which dictate the final price of cocoa can be produced by the clones. This study shows that clonal materials produce beans with high shell content still produce large beans weight, and high fat content. Likewise, smaller beans with high shell content can still produce high fat content. The recovery rate is another attribute that can add value to other physical quality parameters, which is important in terms of economical gain; therefore this parameter needs to be included in selection of the clones.

Clones with high fat content large than 56 % and large bean size (around 1 g) can be selected for breeding and distribute to the farmers. The shell content of the beans becomes secondary importance as clones with high shell content produce large bean weight, and contain high fat content.

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