Performance of Roasted Cocoa Bean Winnower for Smallholder Chocolate Producers

Hendy Firmanto[1*)], Lya Aklimawati[1)] and Bayu Setyo Abdurrizal[1)]

[1)]Indonesian Coffee and Cocoa Research Institute, Jl. PB Sudirman 90 Jember 68118
*)Corresponding author: hendysan@yahoo.com

Abstract

Cocoa bean winnowing has a function to separate cocoa nibs from shell after roasting process of dry bean. Nibs are further processed into fine cocoa liquor by refining process. The aim of this experiment was to evaluate working performance of a home-scale winnower to separate shell from nibs with minimum shell parchment content in cocoa nibs. This experiment was conducted in Postharvest Laboratory at the Indonesian Coffee and Cocoa Research Institute using roasted cocoa bean grade A according to standard of SNI 2323:2008/ Amd1:2010 with shell content of 15% originated from Forastero cocoa. Working performance of the home-scale winnower was evaluated based on shell parchment content in the output, its capacity, energy consumption and power transfer efficiency value by several air suction rates as variable. Data were analyzed using regression and variance analysis to evaluate the influence of the rate and to determine the optimum machine operation. Results of regression and variance analysis from winnowing experiment with air suction rate of 0.54 m/s; 0.63 m/s; 0.72 m/s and 0.90 m/s indicated that shell parchment content in cocoa nibs and power transfer efficiency value were affected by the rate. The optimum machine performance was obtained on 0.72 m/s of air suction rate with total winnowing capacity was 2.615 kg/hour, energy consumption of 132 Watt, power transfer efficiency value of 61.01% and shell parchment content was 1.06%. Shell parchment content in cocoa nibs was appropriate regarding to the SNI standard with maximum content of 1.75%.

Keywords: cocoa, home-scale winnower, air suction, nibs, shell

INTRODUCTION

Cocoa bean roasting in chocolate processing aims to get getting aroma that is obtained from Maillard reactions between reducing sugar compounds and substances of decomposed low-molecular-mass protein decomposition (Rohan & Stewart, 1967). The product of roasting process could be roasted cocoa mass, roasted cocoa nibs or roasted cocoa beans depending on raw materials and machine used (Young-Lee, 2001). Winnower machine separates roasted cocoa beans from shells, consequently roasted cocoa nibs can be processed into cocoa mass (Hartanto, 2012). In using winnower machine, it is expected that the shell texture is fragile as a result it is easier to break and separate. Roasted cocoa beans should also have low water content in order to get uniform fractions of roasted cocoa nibs. Another method to get uniform fractions of roasted cocoa nibs is by sieving the nibs (Becket, 2010).

Previously, type of winnower machine consisted of double rolls with some space

in between for breaking down cocoa beans without grinding them and then sieving the broken beans. Other type was in form of serrated cone cylinder installed to hollowed cone stator widely known as kibbling cones type (Knapp, 1920). The machine was later developed by providing air suction and cyclone-shaped funnel. Roasted cocoa beans are peeled using rotor-stator and then they go to exhausted channel that is connected to suction fan as a results smaller fractions of cocoa shell parchment will be sucked out of the exhausted channel and the nibs are collected on the storage funnel (Beckett, 2009). It is expected that the winnower produces cocoa nibs with uniform size and there is not any tiny cocoa shell parchment mixed with the cocoa nibs (Afoakwa, 2010).

Processing of cocoa beans into confectionary products such as chocolate bar can be done in small-scale in order to get chocolate directly from cocoa beans instead of cocoa mass. Chocolate products made directly from cocoa beans have better flavor and aroma due to self choosing cocoa beans quality by the operator (Purwandaru, 2013). Home-scale winnower machine is developed to encourage farmers and smallholders to process raw cocoa beans from local farms and increasing cocoa basic products produced by home-scale industries in Indonesia (Satriawan, 2007). Winnower machine to produce roasted cocoa nibs was previously developed by Widyotomo (2005) for farmer-group scale and the capacity of the machine was 268 kg/hour. Cocoa processing mechanization using less sophisticated machine is the most suitable for developing home or small-scale industries with relatively low processing cost (Ruf & Siswoputranto, 1995). The objective of this study was to promote home-scale winnower in accordance with chocolate processing in smallholders or even processing run by family farmers.

MATERIALS AND METHODS

The study was conducted in two phases, namely developing the winnower machine and evaluating the performance of the machine and carried out in Post-harvest Laboratory, Indonesian Coffee and Cocoa Research Institute (ICCRI), Jember, East Java. Raw material was research grade A roasted cocoa beans from the bulk cocoa grown in Kaliwining Experimental Station, ICCRI.
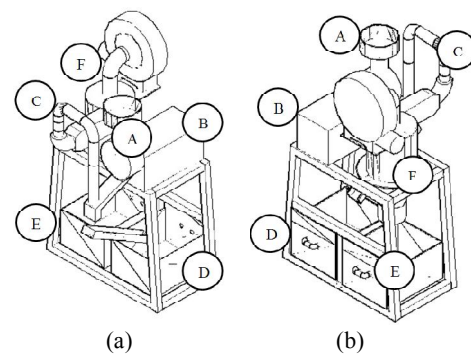
Description of the Machine

Figure 1. Home-scale winnower machine sketch: front side (a), back side (b)

Description:

A. Feeder (feeding tunnel) and peeling rotor-stator

B. Electric motor

C. Cocoa shell suction pipe

D. Cocoa nib exhausted channel

E. Cocoa shell exhausted channel

F. Fan and cyclone

The home-scale winnower machine had five major components, namely feeder, peeler, motor, air suction fan and exhaustion. The feeder consisted of stainless steel funnel of which diameter was 100 mm. The peeler consisted of stainless steel rotor-stator with

blade-shaped rotors and diameter of the rotor-stator 110 mm. The motor was 220 V single phase with 350 rpm and direct transmission system. The suction fan was 40 Watt-electric blower, 50 mm; for sucking cocoa shell parchments from nibs as the result of breaking and or peeling. The machine worked by breaking cocoa beans in the peeler part which result in nibs and shells. The exhaustion had two channels, respectively for cocoa bean nibs and cocoa bean shells. Having two channels for the exhaustion made the recently developed machine more well-organized and practical because it will not take large or separated space but can still work well.

Performance and Cocoa Bean Quality

The home-scale winnower machine performance was evaluated at suction rates of fan, namely 0.54 m/s, 0.63 m/s, 0.72 m/s and 0.90 m/s as well as the quality of cocoa beans produced. Machine working capacity was measured using the following equation:

$$\text{Machine working capacity, kg/hour} = \frac{\text{Roasted cocoa bean input (kg)}}{\text{Peeling duration (hour)}} \tag{1}$$

Power consumption (in Watt) was measured using the following equation:

$$P = I \times V \tag{2}$$

where:

I = electricity current when the machine was working (Ampere)

V = voltage (Volt)

Power transfer efficiency value (çd in percent) was measured using the following equation:

$$\eta d = \frac{n_2 \times d_2}{n_1 \times d_1} \times 100\% \tag{3}$$

n_1 = cylinder axe motor rotation (rpm)

n_2 = main cylinder axe rotation of grinder (rpm)

d_1 = motor diameter (m)

d_2 = grinding axe diameter (m)

During the experiment, there were 10 repetitions of observation and the results were analyzed statistically using regression analysis to evaluate the influence of air-flow rate. One-way analysis of variance (ANOVA) was performed to calculate both F-test and Welch test to determine the effects of different air-flow rate on the capacity of the machine, energy consumption, power transfer efficiency and the quality of output based on the amount of cocoa shells parchments content in the nibs mass.

RESULTS AND DISCUSSION

Winnowing process of cocoa beans functions to eliminate any dirt on the surface of cocoa bean shell by breaking cocoa beans into smaller fractions, cocoa bean nibs and cocoa beans shells and then separating the shell using air suction (Afoakwa, 2010). Air-flow rate of the winnower machine should be maintained accordingly fractions of the cocoa bean nibs are relatively uniform and small fractions from being sucked along with the shell parchment (Beckett, 2008). Beside the amount of cocoa bean shells parchment in cocoa bean nibs mass, air suction rate can also be evaluated based on winnower machine capacity, amount of nibs in shell parchment, power transfer efficiency value and energy consumption.

Shell Parchment in Nibs

The home-scale winnower machine has two main parts connected to each other, the first one peeling cocoa bean shells and the other one separating the shells and nibs attached to the suction fan (Widyotomo *et al.*, 2007). Roasted cocoa beans are peeled by the machine and the results are cocoa bean nibs and lighter fractions of cocoa shell parchment. In the separation process, shell parchments are sucked by the air flow from blower fans because their masses are lighter than cocoa bean nibs (Afoakwa, 2014). The air flow rate should be maintained in order to prevent the shell parchments from being sucked and mixed with the nibs mass. Percentage of shell parchment allowed found in cocoa bean nibs mass or cocoa bean mass products is below 1.75% which is safe for being consumed (Beckett, 2000). Influence of air-flow rate on percentage of shell parchment mixed with the nibs mass was analyzed using regression analysis. Based on the result of the regression analysis presented in Table 1, coefficient of correlation between air flow rate and percentage of shell parchment content was -0.90. It means that both variables have reversed correlation that explains that higher air flow rate result in smaller percentage of shell parchment content in nibs mass. The regression coefficient of -4.28 and t-calculated of -13.00 showed that air-flow rate affected percentage of shell parchment content in the cocoa bean nibs mass; in other words, air-flow rate affected heavier fractions of cocoa bean nibs being sucked by fan.

This experiment used four different air-flow rates, vis. 0.54 m/s, 0.63 m/s, 0.72 m/s and 0.90 m/s with ten repetitions of observation for each air-flow rate. Variance analysis was conducted to find out percentage of shell parchment contents for each of the air-flow rate; after data distribution and variance similarity should be known. Based on the result of One-Sample Kolmogorov-Smirnov test as presented in Table 2, it could be concluded that the data were normally distributed where the level of significance was high (at the 0.05 probability level). The result of variance test of homogeneity using Levene Statistics demonstrated that percentage of shell parchment content was significantly different among the air-flow rates. Therefore, the assumption that there was homogeneity of variance cannot be accepted, as a result the analysis was followed

by Welch test. The test results showed that there was significant difference in percentages of shell parchment content among the air-flow rates.

Based on statistical descriptive analysis shown in Table 4, the results showed that the highest percentage in shell parchment content in nibs was found when the air-flow

Tabel 1. Result of significance by regression analysis

Variable	Coefficient				Standard error				t-Statistic				Prob.			
	A	b	c	d	A	b	c	d	A	b	c	d	A	b	c	d
Constants	-1.19	0.81	-1.21	3.50	0.14	0.08	0.09	0.06	-8.54*	9.65*	-14.37*	62.37*	0.000	0.000	0.000	0.000
Ln air flow rate	-4.28	-0.32	-0.03	-1.31	0.33	0.19	0.21	0.13	-13.00*	-1.62*	-0.15	-9.88*	0.000	0.113	0.879	0.000
R	-0.90	-0.26	-0.03	-0.85				F-Statistic					169.01	2.64	0.02	97.67
R-squared	0.82	0.07	0.001	0.72				Prob. (F-Statistic)					0.00	0.11	0.88	0.00
Adjusted R-squared	0.81	0.04	-0.03	0.71				Durbin-Watson stat					1.47	2.22	2.19	0.73
S.E. of regression	0.39	0.24	0.24	0.16				VIF					1.00	1.00	1.00	1.00
Sum squared resid	5.80	2.10	2.24	0.95												

Notes: a. Shell parchment content, b. Working capacity, c. Energy consumption, d. Power transfer efficiency; * significancy 1%

Tabel 2. Homogeneity variance for different air-flow rates

Diagnostic test	Method	Result of analysis						Conclusion			
		Statistic	Value					a	b	c	d
			A	b	c	d					
Normality	One-Sample Kolmogorov-Smirnov test	Kolmogorov-Smirnov Z	0.36	0.99	0.85	0.94		DN	DN	DN	DN
		Probability	0.99	0.28	0.46	0.34					
Homoskedasti sity	Homogeneity of variance test	Levene Statistics	8.94	1.12	0.41	0.42		DV	NV	NV	NV
		Probability	0.00	0.36	0.75	0.74					
	Welch test	Welch-Stat	68.91	-	-	-		DV	-	-	-
		Probability	0.00	-	-	-					

Notes: a = Shell parchment content; DN = Data is normally distributed; b = Working capacity; DV = Different variance data; c = Energy consumption; NV = Similar variance data; d = power transfer efficiency.

Tabel 3. F test for different air-flow rates parameters (one-way ANOVA)

	Sum of Squares				Df				Mean Square				F				Sig.			
	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
Between groups	-	2.74	0.02	7028.31	-	3	3	3	-	0.91	0.01	2342.7	-	1.52	2.12	112.25	-	0.23	0.12	0.00
Within groups	-	21.58	0.13	751.35	-	36	36	36	-	0.60	0.01	20.87								
Total	-	24.32	0.15	7779.66	-	39	39	39				2342.77								

Notes: a = shell parchment content, c = Energy consumption, b= Working capacity, d = Power transfer efficiency.

Table 4. Statistic descriptive analysis of shell parchment content in nibs at different air-flow rates

Air-flow rate	N	Mean (%)	Std. deviation	Std. error	95% Confidence interval for mean		Min	Max
					Lower bound	Upper bound		
0.54 m/s	10	3.70	0.79	0.25	3.14	4.27	2.60	4.66
0.63 m/s	10	3.28	0.90	0.29	2.64	3.93	2.15	4.90
0.72 m/s	10	1.06	0.33	0.10	0.82	1.29	0.57	1.66
0.90 m/s	10	0.53	0.23	0.07	0.36	0.69	0.25	1.00
Total	40	2.14	1.52	0.24	1.66	2.63	0.25	4.90

rate was 0.54 m/s and the percentage was 3.70%. On the other hand, the lowest percentage of cocoa bean shells mixed in cocoa bean nibs mass took place when the air-flow rate was 0.90 m/s with the percentage was 0.53%. When the air-flow rate was 0.72 m/s, the percentage of the shell parchment content in nibs was 1.06% which was lower than the required (1.75%) and the most acceptable percentage compared to the rests. The fractions of shell parchment have different shapes and weights, therefore relatively large shells with the size almost similar with the nibs, tend to be mixed with the nibs at low air-flow rate. The air-flow rate of this home-scale winnower machine was four times smaller than that of previous winnower machine of with capacity of 268 kg/hour which required 2.8 m/s air-flow rate (Widyotomo *et al*., 2005).

Working Capacity

Cocoa bean consists of two components, namely cocoa bean shells and cocoa bean nibs; where percentage of cocoa bean shells is 11-12% of the total dry weight cocoa beans (Bonvehi, 2004). Home-scale cocoa processing (such as small shops producing chocolate candy) produces products made from dry cocoa beans or cocoa bean nibs to be fine cocoa paste 20-30 micron size (Sira, 2015). Winnower machine capacity is deter-mined by measuring the amount of processed cocoa beans by the machine with regularly input for one hour. The data on Table 1

showed that correlation coefficient was 0.26 which means that there was no correlation between air-flow rate with the capacity of the machine. Similar machine capacity could be achieved if there was no overload input which may hamper the rotor and eventually resulted in excessive friction or vibration (Brennan, 2006).

Variance analysis was conducted to determine optimum capacity of the machine. The analysis was carried out by comparing capacity of the machine with each of air-flow rate Prior conducting analysis of variance, either data distribution or their variance had been confirmed. Based on One-Sample Kolmogorov-Smirnov and Levene Statistics as shown on Table 2, it can be concluded that the data had normal distribution ($\alpha = 0.05$) and capacity of the home-scale winnower machine had the same variance. Variance homogeneity assumption had been fulfilled therefore Anova with F-test analysis can be conducted. Result of F-test showed that the scores of engine capacity for every air-flow rate was the same ($\alpha = 0.05$) as described in Table 4. Engine capacity in average was 2.62 kg/hour as presented in Table 5, using statistic descriptive analysis; when air-flow rate was 0.72 m/s, the working capacity was 2.42 kg/hour. Considering the amount of shell parchment content in nibs mass, the air-flow rate should be used to get optimum capacity of 0.72 m/s.

Tabel 5. Statistic descriptive analysis of working capacity for different air flow-rates

Air-flow rates	N	Mean (kg/hour)	Std. deviation	Std. error	95% Confidence interval for mean		Min	Max
					Lower bound	Upper bound		
0.54 m/s	10	3.04	0.96	0.30	2.35	3.73	2.16	5.54
0.63 m/s	10	2.38	0.35	0.11	2.13	2.63	1.99	2.93
0.72 m/s	10	2.62	1.11	0.35	1.83	3.42	1.84	5.63
0.90 m/s	10	2.42	0.35	0.11	2.16	2.67	2.09	2.95
Total	40	2.61	0.79	0.12	2.36	2.87	1.84	5.63

Energy Consumption

The power of small-scale cocoa processing machine with electric motor such as winnower machine with rotating horizontal cylinder type is 606 Watt for minimum capacity of 5 kg/batch to drive the roasting cylinder (Azizah, 2004). When a machine with small capacity consumes plentiful energy, the operating cost is getting higher. High energy consumption may happen due to overload, loss of energy due to excessive heat transfer or very intensive friction from rotor-stator indicated by excessive heat (Prapti & Novenatus, 2012). The winnower machine consumed energy to move cylinder that breaks cocoa bean shells and to activate fan or blower that suck the broken shells. Table 1 showed correlation coefficient was 0.03 which means that there was no correlation between the air flow rates and energy consumption by the machine. Based on the result of One-Sample Kolmogorov-Smirnov in Table 2, the Kolmogorov-Smirnov Z score was 0.85 and the Levene Statistics score was 0.41; the level of significance was higher than 0.95. Based on the scores, it can be concluded the data were normally distributed and uniform data variance. Therefore, variance homogenity assumption could be accepted and therefore, further analysis using Anova with F-test could be conducted.

Analysis using Anova (Table 4) with F-test showed that there was no significant difference ($\alpha = 5\%$) indicating that among the four air-flow rate there was no signifi-cant difference in energy consumption that was converted into movements for breaking cocoa bean shells and fan suction. Therefore, it can be stated that the machine worked well without any overloading or too intensive fraction. The amount of energy consumption required by the winnower machine was determined using statistical descriptive analysis using normally distributed data ($\alpha = 0.05$) and in average energy consumption had the same data variance.

Result of statistical descriptive analysis as shown in Table 6 indicated that within one hour operation, in average energy consumption of the winnower machine was 136 Watt, while the energy consumption using air-flow rate (0.772 m/s) that met the standard for the amount of shell parchment content in nibs mass was 132 Watt/hour. Compared with previous winnower machine developed by Widayanti (2014), the energy consumption was 833 Watt, air flow rate was 27 m/s, and it could process 167.5 kg of cocoa beans/hour. The required energy for the capacity of winnower machine was still high thus the capacity of input should be increased to achieve optimum capacity since energy consumption did not have any significant influence towards capacity of the machine. Akinnuli *et al.* (2015) stated that for winnower machine with capacity beyond one ton per hour; 1,500 Watt/hour was the amount of energy required to get less than 1.75% percentage of shell parchment content in nibs mass.

Table 6. Statistic descriptive analysis of energy consumption for different air flow-rates

Air-flow rates	N	Mean (Watt)	Std. deviation	Std. error	95% Confidence interval for mean		Min	Max
					Lower bound	Upper bound		
0.54 m/s	10	145	0.06	0.02	0.23	0.32	0.15	0.37
0.63 m/s	10	145	0.05	0.02	0.30	0.37	0.29	0,42
0.72 m/s	10	132	0.08	0.02	0.25	0.36	0.13	0.39
0.90 m/s	10	123	0.05	0.01	0.25	0.32	0.21	0.34
Total	40	136	0.06	0.01	0.28	0.32	0.13	0.42

Power Transfer Efficiency

Power transfer of a machine describes how much power the motor (electric or diesel) could produce and how much of the power can be forwarded to move a cylinder for breaking or peeling cocoa beans. Some factors that affect power transfer efficiency are overload or excessive friction of driving parts due to design of the rotor or transmission system. Weakness of transmission system using V-belt is power from the motor cannot be fully forwarded to drive axe due to rotation slip. Slip occurs because the rubber belt cannot be attached to pulley tightly or surface of the belt has been worn out due to heat effect produced from transmission system when the machine is working. Too much weight may decrease the number of motor rotation caused by friction between material (*cocoa beans*) and rotor-stator inside the unit (Sri-Mulato *et al.*, 2007).

The winnower machine works well when the input material is in form of well-dried and fermented cocoa beans. When the cocoa bean is wet or non-fermented, the texture is hard because the inside structure of cocoa beans are solid (Yusianto *et al.,* 2008). Power transfer of the winnower machine for well-dried and fermented cocoa beans based on Table 1 shows that correlation coefficient was 0.85 which indicated that air flow rate influenced power transfer efficiency. Based on One-Sample Kolmogorov-Smirnov and Levene Statistics analysis shown in Table 2, it can be seen that the data performed normal distribution ($\alpha = 0.05$) and data variance was the same for peeling capacity. Meanwhile, Anova test also showed significant difference among air-flow rates (Table 4) and the level of significance was less than 5%. High air-flow rate will faster suck broken beans inside the rotor as result broken beans will pound or rub the rotor-stator more intensively and eventually higher air flow rate of the blower will reduce power transfer efficiency. Power transfer efficiency that is determined by comparing speed of electric motor and cylinder of the rotor showed that higher air-flow rate of the blower will cause more burden for the rotor cylinder or more intensive friction in the cylinder or in the transmission system (Widyotomo *et al.*, 2011).

In order to find out the amount of power transfer efficiency in different air flow rates and its optimum efficiency, statistical descriptive analysis was carried out. Result of the analysis as presented in Table 7 indicated significant difference in power transfer efficiency as affected by air-flow rate where the lowest was 33.8% while the highest was 65.8%. By considering the most suitable air-flow rate for the amount of shell parchment content in nibs mass (0.72 m/s), the efficiency resulted by the winnower machine was 61.0%. Power transfer efficiency of processing machines might achieve 95.8% or more, similar to the experiment on winnower machine for coffee beans where the optimum power transfer efficiency reached 97.6% (Widyotomo *et al.*, 2011).

Table 7. Statistic descriptive analysis of power transfer efficiency for different air-flow rates

Air-flow rates	N	Mean (Watt)	Std. deviation	Std. error	95% Confidence interval for mean		Min	Max
					Lower bound	Upper bound		
0,54 m/s	10	65.80	6.64	2.10	61.05	70.55	48.34	74.16
0,63 m/s	10	65.55	3.90	1.23	62.76	68.34	58.53	72.44
0,72 m/s	10	61.01	3.29	1.04	58.66	63.37	52.62	64.07
0,90 m/s	10	33.83	3.65	1.15	31.22	36.44	31.51	44.01
Total	40	56.55	14.12	2.23	52.03	61.07	31.51	74.16

CONCLUSIONS

Home-scale winnower machine equipped with air suction can be used to peel roasted cocoa beans with shell parchment content in nibs mass is 1.06% or smaller than the Indonesian National Standard of 1.75%. Winnower air flow rate influences percentage of shell parchment content in nibs mass. The best power transfer efficiency by electric motor occurs when the air-flow rate is 0.72 m/s. In this air-flow rate, the winnower machine has capacity of 2.62 kg/hour, energy consumption 132 Watt and power transfer efficiency 61.0%.

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