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A Study on the Breaking and Winnowing Machine for Cocoa Beans at Small Industrial Scale in Vietnam

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***Abstract*— In the chocolate or cocoa powder processing process, the roasted cocoa beans have to pass to the breaking and winnowing step to obtain the nibs. The quality of chocolate or cocoa powder depends strongly on the amount of shell that is not separated and still mixing on the nibs. Recently, most of the cocoa bean breaking machines are based on the principle of grinding. This leads to some disadvantages as (1) the shells might be not separated from the cocoa kernel after the shattering that results in low efficiency of the cleaning process (<96%); and (2) the nibs are also crushed so much to become smaller so that they are easy to moving out together with the shell in the winnowing step due to the similar density. As a result, the ratio of nibs loss during the cleaning process is very high as around 11.3%. Therefore, the shattering and cleaning process has strongly affected the economic efficiency of cocoa production. One of the new methods for cocoa breaking and winnowing in order to increase the cleanness level and to reduce the nibs loss rate has been developed and studied. The cocoa seeds breaking based on the centrifugal mechanism in combination with the pneumatic cleaning have been conducted to manufacturing breaking and winnowing machine with a capacity of about 80 kg/hour. The experimental results indicate that the efficiency of the cleaning process rises to more than 99% and the ratio of nibs loss reduces to 1.6% only which leads to increase the economic efficiency of the cocoa processing process.**

***Keywords*— breaking cocoa seeds; winnowing cocoa nibs; nibs; chocolate and cocoa powder.**

I. INTRODUCTION

Growing in Central America over five thousand years ago, cocoa beans have been primarily used as main raw material for chocolate and other confectionery products in the world, for example, recently there have more than 90% of the worldwide cocoa beans produced are used for chocolate production. It is one of the major crops of several countries with a total crop of 4,739 metric tons annual. According to the UN Food and Agriculture Organization (FAO), these are the top cocoa producers in the world as presented in Table 1 which indicates that cocoa is most commonly grown in Côte d'Ivoire and supplied up to 30 percent of the world's total cocoa, see more at [1].

The demand for cocoa in countries is continually increasing, and production has not met the requirements [2]. As cocoa demand remains significantly high around the world, driven by the strong performance of the global chocolate industry, these top cocoa producing countries are expected to further strengthen their leadership in the global cocoa production and create more business opportunities for local cocoa suppliers [2].

In Vietnam, according to the report of the Department of Crop Production, Ministry of Agriculture and Rural Development in 2015 [3], the area of cocoa is around 22,300 ha and mostly develops in the two largest growing areas as the Mekong River Delta and the Central Highlands [4]. However, the harvested area recently is about 11,055 hectares, accounting for 50% of the total planted area which leads to the output of dried cocoa beans in Vietnam is not so high with about 4,000 tons annually [3].

In cocoa and chocolate producing at the factory scale, the cocoa processing flow in the world is presented in Fig.1 [5]. The resulting pieces of beans are called nibs. They are sometimes sold in small packages at specialty stores and markets to be used in cooking, snacking, and chocolate dishes. Since nibs are directly from the cocoa tree, they contain high amounts of the bromine. Most nibs are ground, using various methods, into a thick, creamy paste, known as chocolate liquor or cocoa paste. This "liquor" is then further processed into chocolate by mixing in (more) cocoa butter and sugar (and sometimes vanilla and lecithin as an emulsifier), and then refined, conceded and tempered. Alternatively, it can be separated into cocoa powder and cocoa butter using a hydraulic press or the Broma process. This process produces around 50% cocoa butter and 50% cocoa powder [6].

One of the most important processing steps is the defueling of cocoa beans in which how to prevent nib loss that is the valuable part of the cocoa bean in order to ensure

maximum yield. It is easy to see that there have many steps in the production line for cocoa processing [7]. The cocoa processing machines in the world are stable and completely during some last decades and according to the large industrial scale production [7]. In opposite, most of the cocoa processing plants in Vietnam are built at the small industrial scale due to the small yield of cocoa produced yearly. This leads to the cocoa processing factories in Vietnam might not be equipped with modern machines like in some famous plants in the world. Recently, most of the cocoa plants in Vietnam using the grinding method to the separation of the nibs and shell. The winnower includes a screen raking system.

TABLE I
THE YIELD OF COCOA PRODUCTION IN 2012- 2017 IN SOME COUNTRIES [2].

Rank	Country	Production (tons)
1	Cote d'Ivoire	1,448,992
2	Ghana	835,466
3	Indonesia	777,500
4	Nigeria	367,000
5	Cameroon	275,000
6	Brazil	256,186
7	Ecuador	128,446
8	Mexico	82,000
9	Peru	71,175
10	Dominican Republic	68,021

Furthermore, the nibs that are the main material for produce the cocoa powder or chocolate and butter have been received from the dried cocoa beans after passing the breaking and winnowing step play a vital role in the quality of chocolate or cocoa powder. When the nibs are still mixed with the shell in the shattering and cleaning step, the quality of powder and liquor using for produce chocolate decrease so much and as a result, the economic efficiency might be going down. Therefore, a study for developing the breaking and winnowing machines using in a cocoa processing at the small industrial scale in Vietnam is essential and realistic. This paper presents the centrifugal breaker in combination with the pneumatic winnower applied for cocoa processing process to increase the cleanliness and to reduce the rate of *nibs* loss.

II. MATERIAL AND METHOD

The process of producing cocoa nibs from cocoa beans is shown in Figure 1. It can be seen that there have two methods for breaking and winnowing step in the cocoa processing. The first one is that the beans might be roasted before going to the breaker and winnower to produce the nibs. The other one is the bean can be broken and winnowed first to make the nibs before they move to roast step. In this study, the first one has been selected in which the cocoa beans were roasted before going to the breaking than to the winnowing step.

A. Experimental material

The cocoa beans used in the experiment was obtained from the cocoa farm in Ben Tre province, one of the provinces in the Mekong River Delta of Viet Nam (Figure 2) that is mainly kind of the *Trinitario* plant. The cocoa beans used as the experimented samples were removed husk [8] and were selected completely randomized in which they have the same source of cocoa beans and the same roasted regime. The fresh cocoa beans were exposed under the sun – direct than going to dryer [9], [10] as shown in Fig. 3 for drying before passing to the roasting step. The specific weight and the moisture content of roasted cocoa beans is about 570 kg/m^3 and from 3.5% to 4.2%, respectively.

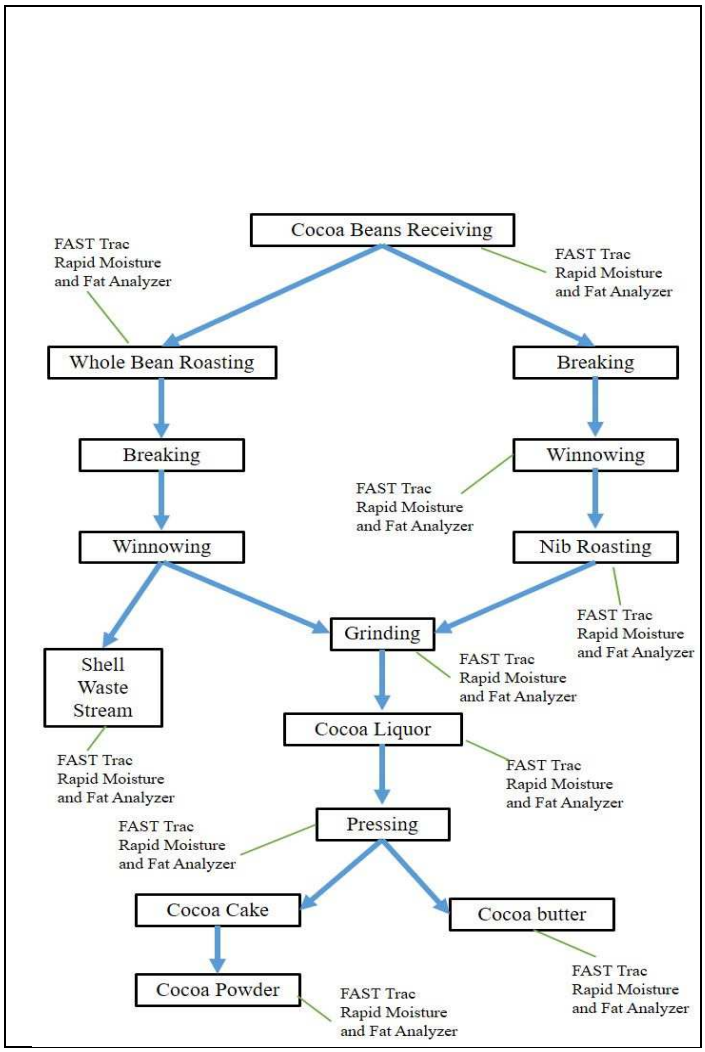


Fig. 1 The process of producing nibs from cocoa beans [5]

Fig.2 The cocoa beans used in the experiment come from Mekong River Delta (MRD)

TABLE II
THE MASS PERCENTAGE OF THE NIBS IN THE COCOA BEANS

Sample code	Sample Mass M(g)	Mass of the nibs(g)	The mass percentage of the nibs in the cocoa beans (%)
01	101.5	79,72	78.5
02	100.26	81.01	80.8
03	100.71	78.95	78.4
Average			79.2

B. Parameters Define and Study Methods

The determination of the shell ratio in roasted cocoa beans using for the experimental study was investigated by manual as presented in figure 4. Some roasted cocoa beans were weighted as M (gram), normally taken for about 100 beans, then these beans were separated their shell by hand, and the mass of nibs was m (gram). The percentage of nibs in the cocoa beans (P*nibs*) is defined as the ratio between the mass of nibs and the mass of cocoa beans counted by percentage as

$$P_{nibs}\_T = m / M * 100\% \quad (1)$$

(a) (b)

Fig. 3 The fresh cocoa beans (a) and exposed under the sun –direct (b) used in the experiment

Fig. 4 Manual investigation to determine the *nibs* percentage in the roasted cocoa beans

The cleanness of the winnowing step is defined as the ratio between of mass of nibs (a: gram) and the total mass of mixing of nibs and shell (A: gram) after winnowing counted by percentage as £ = a/A *100 (%). Table 2 presents the percentage of nibs in the cocoa beans. It is clear that the maximum percentage of the nibs in the roasted cocoa beans is P_{nibs_T} = 79.2% when the cleanness is £ = 100%. The *nibs* losses ratio during the breaking and winnowing step is defined as the ratio of the maximum mass of nibs (m) and the mass of nibs received after winnowing step. To count this parameter, taking 10 kg of roasted cocoa called (X) put into the breaker and winnower then measuring the mass of nibs in final as:

$$P_{nibs}\_p = X * £/10 * 100\% \quad (2)$$

The *nibs* losses will be counted as

$$L = (P_{nibs-T} - P_{nibs-p}) * 100\% \quad (3)$$

1) Experimental layout: The experiments were completely randomized, repeated three times.

2) Experimental data processing: The data were analyzed by using the variance analysis to evaluate the deviation of the experimental value, the correlation of the study factors and the suitability of the experimental statistical model.

C. Experiment devices

Drying machine: In order to reduce the moisture content of the fresh cocoa beans required before going to the roasting step [10], the flatbed dryer has been used in the experiment as is the same with the author's device used in ref. [11],[12]. The dryer operation principle is the axial fan (1) flows fresh air from outside through the resistance used electricity to increase the temperature of the air. Then, the hot air is forced through the drying chamber via the windscreen wing and the two distributed doors. The dryer is manufactured with the drying agent might be reserved and the temperature is controlled automatically by using the sensor with PID procedure. Therefore, during the drying process, the drying agents can be reversed so that the cocoa beans might be uniformly dried.

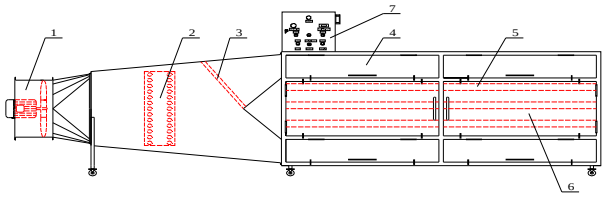


Fig. 5 Dryer used for experiments [11] 1. Fans, 2. Resistivity, 3. Wind wing, 4. Drainage door, 5. Drying tray, 6. Drying door, 7. Electric control cabinet.

1) Roasting machine: Cocoa beans roasting is one of the most important steps in determining the quality of chocolate and cocoa powder [10]. The quality of the nibs after roasting depends strongly on ripeness level of harvested fresh cocoa, roasting temperature and roasting time. The roasting temperature is normally decided to base on the purpose of processing chocolate or cocoa powder. In order to conduct the experimental study, the roasted machine has been developed in our Lab in the Nong Lam University Hochiminh city, Vietnam. The rotary drum roasting type with indirectly heated at the bottom is the main device of the roasting machine has been selected and manufactured (Figure 6a). The machine is powered by 01 HP electricity engine, heating supported by using LPG gas and its cross weight is around 137 kg (Figure 6b).

Cocoa beans are poured into feeder (1) through the beans adjusted supplier (2) then they move to the drum roaster (3) where the beans are continuously stirred and heated by the heat supplied through the infrared gas burner (5). During the roasting, the roasted time has been set up just enough for the cocoa beans ripen. The moisture content is absorbed by the exhaust fan (7) to moving out to the external environment. After roasting finished, the cocoa beans are removed through the roasted bean exit door (4). The experimental testing parameters are the roasting temperature and time are set up as 114^0C and 26 minutes, respectively for the productivity of 10kg / batch. The moisture content of cocoa beans in this step reduces from 6.36% to 3.23% which is satisfactory for processing.

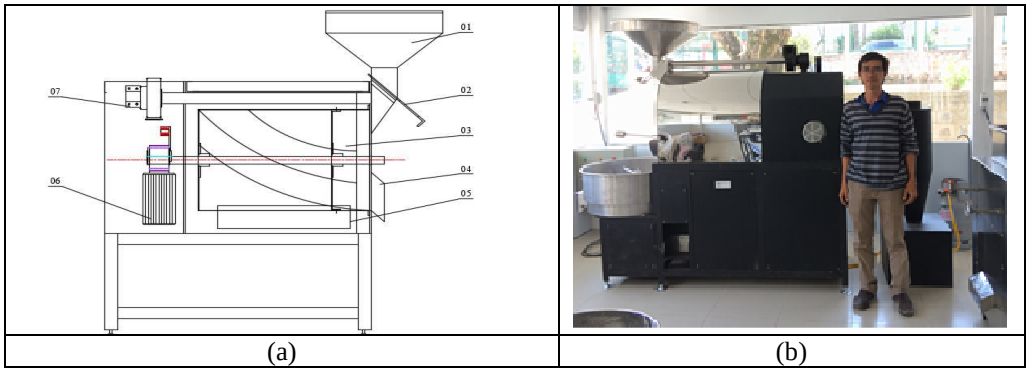


Fig. 6 (a) Roasting machine with the capacity of 10kg / batch working principle diagram. 1. Feed hopper; 2. Beans adjusted supplier; 3. Drum roaster; 4. Roasted bean exit; 5. Infrared gas burner; 6. Engines; 7. Suction fans. (b) Roasting machine with the capacity of 10kg / batch

III. Result and Discussion

Breaking and winnowing are two steps which might lead to increase the economic efficiency and the quality of nibs in the cocoa processing. In order to develop a suitable cocoa breaking and winnowing in the processing system with high cleanness and low nibs rate loss, in this study, two kinds of breaking and winnowing machines have been studied, manufactured and experimentally investigated. The first one of breaker use the grinding method and the second one is centrifugal breaking.

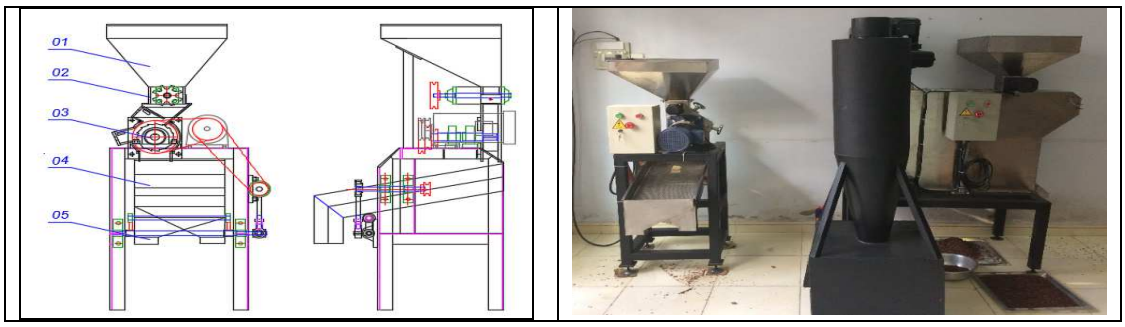
A. Developing the Breaker and Winnower Using the Principle of Crushing and Grinding

As the analysis above, most of cocoa processing system consists of the cocoa breaker that cracks the whole roasted bean and screening with a pneumatic air-flow winnower that separates the broken shells from the nibs. The breaker is developed by applying the principle of grinding teeth to breaking cocoa beans which is recently popular in the cocoa processing system in Vietnam as shown in Fig.7. In operation, cocoa beans are fed into the inlet hopper of the breaker (1) and pass to beans agitator (2) before going to the breaking part (3). The specially engineered agitator and adjustable breaking part will shear the beans to avoid unnecessary crushing. The broken shells and nibs fall into a screen raking system (4) that maintains the flow of product through the screens as shown in figure 7a-b. The broken mixture is then fed carefully into the winnower where an adjustable air current separates the broken shell from the nib. The winnower collects shell debris by using a vacuum system as presented in figure 7.

Using the grinding breaker and winnower developed, the experimental investigation has been conducted to determine the rate of *nibs* recovery, the cleanness and the rate of loss. Table 3 presents the cleanness of cocoa beans in the processing system with the breaker applied grinding principle. It might be seen that the cleanness is not too high, around 95%, which leads to reduce the rate of nibs recovery and also affect strongly to the quality of nibs of the cocoa processing system. The experimental investigation results show that there have some cocoa beans have high collision force between shell and beans so that the shells are still attached to the cocoa cover and the grinding teeth for breaking cannot separate the nibs and shell. As a result, the nibs and shell are still mixing (figure 8) and the cleaner cannot work for separating mixture product as shown in figure 9. The rate of *nibs* recovery during the processing is

shown in table 4. It is noted that this rate is measured for the mixture in which there have some shell and nibs attached after winnowing step. Therefore, the real rate of *nibs* recovery is counted as:

Real recovery rate (%) = the cleanness £ (%) *Recovery rate (%) =0.958 * 70.9 = 67.9 (%).



(a) (b)

Fig.7 (a) The structure Diagram of the breaker with the principle of grinding 1. Feed hopper; 2. Beans agitator; 3. the breaking part; 4. Screening; 5. Nibs exit door (b) Breaking according to the principle of grinding and cleaning according to the principles of aerodynamics

Comparing with the maximum mass percentage of the nibs in the cocoa beans (%) shown in Table 2, it is easy to infer that the rate loss of nibs during the processing with these machines is 11.3% (79.2 - 67.9). The high rate of loss might be caused by some reasons, such as the grinding principle might easily crush the nibs become smaller parts. Hence, they are easy to be blown together with the shell in the winnowing step due to the density of them is not quite different; and the grinding principle might be not suitable to separate the nibs moving out from the shell as presented in figure 9. As a result, there have some nibs throwing out with the shell during the processing.

The breaker using the principle of centrifugal breaking has been developed and investigated experimentally to overcome some disadvantages of the grinding principle applied in the cocoa processing system as low cleanness and high rate of *nibs* loss. The breaker mechanism is basing on the centrifugal force that comes from the dish rotation affects directly to the cocoa beans. The momentum forces to the bean so that the cover shell would be broken for separating. Figure 10 and figure 11 present the schematic diagram and the centrifugal breaking and cleaning machine for cocoa beans processing developed by this study with capacity is 80kg/h, respectively.

TABLE III
THE CLEANNESS BY BREAKER APPLIED GRINDING PRINCIPLE.

Sample	the total mass of nibs and shell A(g)	the total mass of nibs a(g)	Cleanness £ (%)
01	127,51	121,45	95.2
02	102,48	98,32	95.9
03	153,04	147,28	96.2
Average			**95.8**

TABLE IV
THE RATE OF NIBS RECOVERY

Sample	Mass of cocoa sample (kg)	Mass of nibs (kg)	Recovery rate (%)
01	10	6.91	69.1
02	10	7.1	70.4
03	10	7.33	73.3
Average			**70.9**

Fig. 8 The Nibs and shell still mixing after processing used grinding Principle

Fig. 9 The nibs still attached with the shell after processing

B. Developing the Breaker and Winnower Using the Principle of Centrifugal Breaking

For operation, the roasted cocoa beans are supplied to the centrifugal breaking device (2) from the feeding hopper (1) where it responds for storing and supplying roasted cocoa beans during the breaking step. The mixture of shell and nibs after the breaking will be transferred to the screen (5) by the elevator (3). The screen (5) will separate the nibs into different sizes and continuously to the cleaning unit (4) for removing the shell. After removing the shell, the nibs are collected.

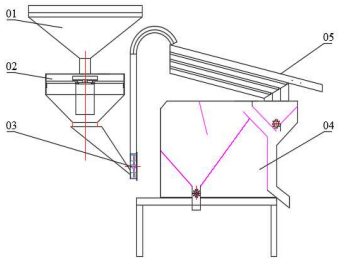


Fig. 10 Schematic diagram of centrifugal breaking and cleaning of cocoa beans with capacity is 80kg/h.

1. Feeding hopper; 2. The centrifugal breaking device; 3. Mixture nibs and shell elevator; 4. Cleaning section; 5. Screen grain size classification

Fig.11 Centrifugal blower and cleaning according to the aerodynamic principle

The experimental investigation has also been conducted with these machines. Similarly, as above, the cleanness, the rate of *nibs* recovery and the loss rate have been tested. Table 5 shows the cleanness of cocoa beans when using the breaker applied the centrifugal principle. The cleanness is very high, around 99.1% so that it is strongly to recommend using this principle for the breaking step. This would contribute to increase the rate of *nibs* recovery shown in table 6 and reduce the loss rate as well as affect the quality of nibs of the cocoa processing system. Furthermore, the real rate of nibs recovery is counted as Real recovery rate (%) = the cleanness £ (%) *Recovery rate (%) = 99.1 * 78.3 = 77.6 (%)

Similarly, compared with the mass percentage of the nibs in the cocoa beans (%) shown in table 2, it is easy to infer that the rate loss of nibs during the processing is 1.6 % (79.2 – 77.6). It is clear that the loss rate is very low with the breaker used centrifugal breaking principle.

TABLE V
THE CLEANNESS BY BREAKER APPLIED CENTRIFUGAL PRINCIPLE.

Sample	The Total Mass of nibs and shell A(g)	The Total Mass of nibs a(g)	Cleanness £ (%)
01	104.38	103.45	99.1
02	126.15	125.17	99.2
03	119.2	117.82	98.8
Average			99.1

Fig.12 The nibs after breaking and winnowing used centrifugal principle

TABLE VI
THE RATE OF NIBS RECOVERY

Sample	Mass of cocoa sample (kg)	Mass of nibs (kg)	Recovery rate (%)
01	10	7.91	79.1
02	10	7.74	77.4
03	10	7.86	78.6
Average			**78.3**

Figure 13 and figure 14 present the results of the cleanness rate and the loss rate of nibs between two principles of breaking and winnowing. Due to the cleanness rate increases significantly with the centrifugal breaking principle, the loss rate of nibs during processing is very low as shown in figure13. This rate is lower than around seven times compared with the one applied the grinding breaking principle. Therefore, it is clear that the economic efficiency of the cocoa processing using the centrifugal breaking principle would be higher than the one applied the grinding principle.

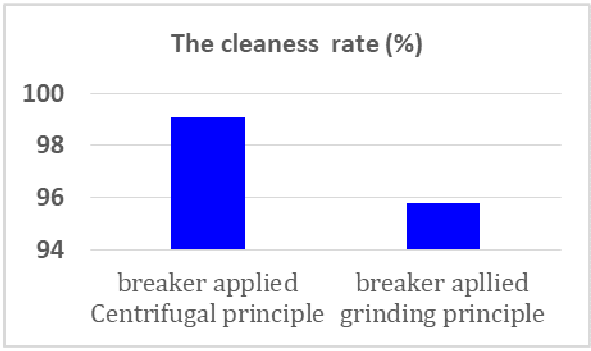


Fig. 13 The cleanness rate of nibs between two principles of breaking and winnowing

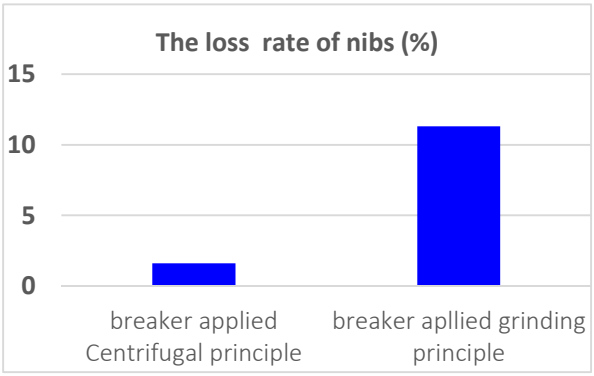


Fig.14 The loss rate of nibs between two principles of breaking and winnowing

IV. CONCLUSIONS

This study has presented the breaker and winnower developed for the cocoa beans processing at small industrial scale. One of the new principle for cocoa breaking and winnowing in order to increase the cleanness level and to reduce the *nibs* loss rate has been studied and developed. The cocoa beans breaking based on the centrifugal mechanism in combination with the pneumatic cleaning have been conducted to manufacturing breaking and winnowing machine with capacity of about 80 kg/hour. The experimental results present that the efficiency of the cleaning process rises to more than 99% and the ratio of nibs loss reduces to 1.6% only which leads to increase the economic efficiency of the cocoa processing process.

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