Design of a separation machine using pneumatic system combined with sieve vibration for removing parchment coffee from Robusta green coffee bean

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Abstract. The hulling process for coffee bean extraction may not effectively release the bean from parchment. This might negatively affect the aroma or taste of coffee in the coffee beans roasting process. Consequently, the objectives of this work were to design and construct a machine for separating parchment coffee from Robusta green coffee bean using a pneumatic separation system combined with sieve vibration. The performance of the separation machine was investigated under different operating conditions such as air velocity, vibration frequency, and the angle of sieve inclination. The samples were fed into the machine at a feed rate of 20 kg/h. The testing conditions were set at air velocities of 2 to 4 m/s, vibration frequencies of 36 to 40 Hz, and sieve inclination angle of 4° to 8°. The results showed that the purity and separation efficiency of parchment increased with increasing air velocity. Conversely, decreasing vibration frequency and sieve angle increased the purity and separation efficiency. The appropriate conditions for parchment coffee separation from Robusta green coffee bean using a pneumatic-sieve vibration system were 4 m/s air velocity, 36 Hz vibration frequency, and 8° sieve angle with the highest overall effectiveness of 92%.

1. Introduction
Coffee has major economic significance for both production and consumption in the Thailand markets. Robusta coffee or Coffea canephora reports a high production of coffee in Thailand [1]. There is major export production in southern Thailand, which amounted to about 25 thousand bags in February 2020 [2], mainly used as a raw material of instant coffee. The coffee cherries go through the coffee bean processing into the finished coffee ready for the roasting process by several methods such as dry method, semi-dry method, and wet method [3]. However, the dry method is widely used because of its simplicity, less water, and machinery requirements. The dry method has two steps; drying and hulling the cherries to produce green beans. The hulling process properly removes cherry fruit (skin, pulp, and parchment) from the bean via hand mills or hulling machines. The removing parchment coffee from Robusta green coffee beans can have a significant effect on the final quality of the green coffee since it is playing an important role in aroma formation or taste during the roasting process. After hulling, coffees are sorted into screen sizes, and defect sorting takes place.

In the hulling process, the sorting of parchment coffee from the green coffee bean is done manually, using vibrating sieves, and pneumatic separation system to separate the parchment coffee from green coffee beans before milling. The vibrating sieves operation is a screening process based on the movement of materials, the mesh size of the sieve, and the direction of movement of the sieve [4]. However, there might result in increased grain losses since the grains stick together on the sieve [5, 6].
The pneumatic separation involves lifting up lightweight materials from the grain, while heavier materials move downward by the airflow [7]. However, the low degree of separation is a limitation of the pneumatic separation system [8]. Additionally, the pneumatic separation system is currently ineffective and unsatisfactory since green coffee beans are small, resulting in low porosity values. High separation efficiency for the pneumatic system is probably due to the installation of specially designed devices that stabilize the uniformity of coffee bean distribution. Therefore, a vibrating separator with a sieve is a good alternative to distribute coffee during the hulling process.

Generally, the hulling process may not effectively release the bean from parchment. Therefore, this study aimed to design and construct a machine for separating parchment coffee from Robusta green coffee bean using a pneumatic separation system combined with sieve vibration. The performance (purity of separated parchment, separation efficiency, and overall effectiveness) of the separation machine was investigated under different operating conditions such as air velocity, vibration frequency, and sieve angle.

2. Materials and methods

2.1. Materials

Robusta green coffee beans and parchment coffee were produced and harvested in Chumphon Province in the south of Thailand, as shown in figure 1. Robusta green coffee beans were used in this study without the size selection process and a moisture content of 9.8% dry basis. The moisture content of parchment coffee was 8.5% dry basis. The samples, 0.9 kg green coffee bean, and 0.1 kg parchment coffee, were used, and the green coffee beans in the samples were sprayed to clearly identified samples.

![Figure 1. Robusta green coffee beans without a parchment coffee (a), parchment coffee (b), and the samples (a mixture of green coffee beans and parchment coffee) (c)](image)

2.2. Experimental apparatus

The separation of the parchment coffee and Robusta green coffee bean is done on sifting sieves supported with a pneumatic system, as shown in figure 2. The design of the machine involved developing and assessing the performance of separation. The separation machine consists of a pneumatic system of rectangular cross-section width of 300 mm and a depth of 150 mm. A pneumatic system is supplied by a centrifugal blower with 1 hp, which is fitted below the sieve vibration system. The sieve vibration system is 90 cm in length and 70.2 cm in width with an aperture size of 0.3 mm. The sieve was installed on an inclined plate and connected to a frame by bolts to change the angle of sieve inclination (2). Two motors drive the vibration system with 0.18 kW.

The samples (a mixture of green coffee beans and parchment coffee) were fed into the hopper (1) to be distributed and separated by a pneumatic system combined with sieve vibration. The sieve vibration system and sieve inclination angle were adjusted, then the experiment was started. All experiments were conducted with the samples at a feed rate of 20 kg/h. Afterwards, green coffee bean and parchment coffee were collected separately in outlets (3) and (4) and weighed using electronic balances.
2.3. Experimental procedure
The performance of the separation machine was investigated under different operating conditions such as air velocity, vibration frequency, and sieve angle. The samples were fed into the machine at a feed rate of 20 kg/h. The testing conditions were set at air velocities of 2 to 4 m/s, vibration frequencies of 36 to 40 Hz, and sieve inclination angle of 4° to 8°. The number of green coffee bean and parchment coffee was recorded to evaluate the performance of the separation machine. The purity of separation, separation efficiency, and overall effectiveness was determined using equations (1)–(11).

The purity of separated coffee bean or parchment coffee was determined by the ratio of the coffee bean or parchment coffee to the total weight of their samples, which fed into the hopper using the formula below:

\[ P_{CB} = \left( \frac{W_{CB} - q_{PC}}{W_{CB}} \right) \times 100 \]  
\[ P_{PC} = \left( \frac{W_{PC} - q_{CB}}{W_{PC}} \right) \times 100 \]

where:
- \( P_{CB} \) – the percentage purity of coffee bean after separation, %;
- \( P_{PC} \) – the percentage purity of parchment coffee after separation, %;
- \( W_{CB} \) – the weight of all samples in the coffee bean outlet, g;
- \( W_{PC} \) – the weight of all samples in the parchment coffee outlet, g;
- \( q_{CB} \) – the weight of coffee bean outlet in the parchment coffee outlet, g;
- \( q_{PC} \) – the weight of parchment coffee in coffee bean outlet, g;

The separation efficiencies of the coffee bean (ECB) and parchment coffee (EPC) were determined based on the weight of mixture components. The separation efficiency of each component was calculated with the formula below:

\[ E_{CB} = \frac{W_{CB} - q_{PC}}{Q_{CB}} \times 100 \]  
\[ E_{PC} = \frac{W_{PC} - q_{CB}}{Q_{PC}} \times 100 \]

where:
- \( Q_{CB} \) – the weight of coffee bean, g;
- \( Q_{PC} \) – the weight of parchment coffee, g.

The overall effectiveness (\( \eta \)) is a measure of performance of the separating parchment coffee from a coffee bean, indicating a relationship between the separating ability, purity, and separation efficiency. The overall effectiveness was calculated with the formula below:
\[ \eta = \left[ F_{CB} \left( \frac{p_{CB} - q_{CB}}{1 - a_{CB}} \right) + F_{PC} \left( \frac{p_{PC} - q_{PC}}{1 - a_{PC}} \right) \right] \times 100 \] (5)

The separating ability of material, purity, and separation efficiency was determined with the following formula:

\[ F_{CB} = \frac{W_{CB}}{W_T} \] (6)

\[ F_{PC} = \frac{W_{PC}}{W_T} \] (7)

where: 
- \( F_{CB} \) – separating ability of material in coffee bean outlet;
- \( F_{PC} \) – separating ability of material in parchment coffee outlet;
- \( W_T \) – the weight of all samples, g.

\[ p_{CB} = \frac{W_{CB} - q_{PC}}{W_{CB}} \] (8)

\[ p_{PC} = \frac{W_{PC} - q_{CB}}{W_{PC}} \] (9)

where:
- \( p_{CB} \) – purity of coffee bean after separation, %;
- \( p_{PC} \) – purity of parchment coffee after separation, %.

\[ a_{CB} = \frac{Q_{CB}}{W_T} \] (10)

\[ a_{PC} = \frac{Q_{PC}}{W_T} \] (11)

where:
- \( a_{CB} \) – the ratio of coffee bean weight to the total weight of the samples;
- \( a_{PC} \) – the ratio of parchment coffee weight to the total weight of the samples.

All experiments were carried out triplicate, and all data were expressed as the mean ± SD. The differences in mean values were evaluated by one-way analysis of variance (ANOVA) using SPSS. The result of ANOVA does not provide detailed information regarding the differences among various combinations of groups. The analysis of the differences between particular pairs of experimental groups was performed by using the LSD method as the multiple comparison test. The values with the same letter were significantly different (P < 0.05).

3. Results and discussion

3.1. The separation efficiency of green coffee bean and parchment coffee

The influence of various operating parameters were investigated at air velocities of 2 to 4 m/s, vibration frequencies of 36 to 40 Hz, and sieve inclination angle of 4° to 8°. The variations in the separation efficiencies of green coffee bean and parchment coffee are presented in figures 3 and 4. The separation efficiencies of the green coffee bean at a sieve inclination angle of 4° and vibration frequency of 36 Hz decreased from 76.1% to 65.7% when the air velocity increased from 2 to 4 m/s. However, the separation efficiencies of the parchment coffee at a sieve inclination angle of 4° and vibration frequency of 36 Hz increased from 87.4% to 96.7% when the air velocity increased from 2 to 4 m/s. The separation efficiency of the green coffee bean slightly decreased with increasing air velocity, while the separation efficiency of parchment coffee increased. These results indicated that the green coffee bean and parchment coffee might be passing through the parchment coffee outlet at high air velocity in a pneumatic system.

On the other hand, the separation efficiency of the green coffee bean at a sieve inclination angle of 8° increased to 99.2% at a high air velocity of 4 m/s and vibration frequency of 40 Hz. In contrast, the separation efficiency of parchment coffee decreased to 89.3%. This suggested that the green coffee bean and parchment coffee had been quickly distributed by sieve vibration, which restricted the pneumatic system from blowing the coffee beans into the wrong outlet channel. In addition, the increase in air velocity coupled with an increasing sieve inclination angle from 4° to 8° might have
caused the rising movement of coffee beans into the coffee bean outlet. Our result is consistent with Srisang et al. [9] that the sieve inclination angle significant effect on separation efficiency. As a result, the separation efficiency of the green coffee bean was found to have increased with increasing the angle of inclination.

**Figure 3.** Separation efficiency of green coffee bean with different sieve inclination angles, air velocities, and vibration frequencies.

**Figure 4.** Separation efficiency of parchment coffee with different sieve inclination angles, air velocities, and vibration frequencies.

### 3.2. The purity separation of green coffee bean and parchment coffee

The amount of green coffee bean and parchment coffee in both outlets were weighed to assess the purity of separated parchment coffee from green coffee beans. The percentage purity of separation presented in figures 5 and 6 at different sieve inclination angle, and vibration frequency, the purity separation of green coffee bean increased with increasing air viscosity from 2 to 4 m/s. These suggested that high air velocity is more efficient in separating parchment coffee from coffee beans. However, the parchment coffee outlet still had a mixing of samples due to high air velocity conditions. This indicated that the purity of separated parchment coffee slightly decreased (figure 6). The purity separation of green coffee beans gradually decreased when vibration frequency increased from 36 to 40 Hz and at different levels of sieve inclination angle since the parchment coffee was also found in the green coffee bean outlet. These results were consistent with the significant drop in the separation efficiency of parchment coffee in the same conditions. However, the purity separation of parchment coffee increased when the vibration frequency and sieve inclination angle increased.

### 3.3. The overall effectiveness of green coffee bean and parchment coffee

The overall effectiveness of the separation was calculated from the separation efficiency and purity of separated of coffee bean and parchment coffee. The variations of the overall effectiveness of removing parchment coffee from Robusta green coffee bean under different conditions are shown in figure 7. The overall effectiveness of this separation machine using a pneumatic system combined with sieve vibration ranged between 59.3 and 92.2%. The appropriate condition for parchment coffee separation from green coffee bean was 4 m/s air velocity, 36 Hz vibration frequency, and 8° sieve inclination angle with the highest overall effectiveness of 92.2%. In this condition, the separation efficiencies of the green coffee bean and parchment coffee were 97.8% and 93.6%, respectively, and the purities separation of the green coffee bean and parchment coffee were 99.4% and 82.6%, respectively.
Figure 5. Percentage purity of separated green coffee bean with different sieve inclination angles, air velocities, and vibration frequencies.

Figure 6. Percentage purity of separated parchment coffee with different sieve inclination angles, air velocities, and vibration frequencies.

Figure 7. Overall effectiveness of removing parchment coffee from Robusta green coffee bean with different sieve inclination angles, air velocities, and vibration frequencies.

4. Conclusions
This study was designed to investigate parameters affecting the separation efficiencies for the novel separation machine for removing parchment coffee from Robusta green coffee beans. The operating conditions such as air velocities of 2 to 4 m/s, vibration frequencies of 36 to 40 Hz, and sieve inclination angle of 4° to 8° were conducted using a separation machine with a pneumatic system combined with sieve vibration. The results show that increasing air velocity and decreasing vibration frequency and sieve inclination angle in separating parchment coffee from Robusta green coffee beans increased the separation efficiency of parchment coffee and the purity separation of green coffee beans. The highest overall effectiveness for parchment coffee separation from green coffee bean was 92.2% at an air velocity of 4 m/s, vibration frequency of 36 Hz, and sieve inclination angle of 8°. Additionally, further work on the size grading of green coffee beans using these methods is needed to find optimal operating conditions that enhance the performance of coffee processing and designing of the separating machine.

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