The Increase of Efficiency in Robusta Green Coffee Bean Size Sorting Machine by Response Surface Methodology

Watcharapong Chanpaka, Naruebodee Srisang, Panya Dangwilailux and Thatchapol Chungcharoen

Engineering Department, King Mongkut’s Institute of Technology Ladkrabang, Prince of Chumphon Campus, Chumphon, Thailand

Corresponding author’s e-mail: thatchapol.ch@kmitl.ac.th

Abstract. One of the essential processes for producing the green coffee bean with Robusta variety is size sorting process because it is able to add the value of green coffee bean. The excellent size sorting can be done by using the size sorting machine. In this study, the size sorting machine with revolved sieve which provided the good distribution of green coffee bean was used and the three factors such as sorting angle, revolved speed and feed rate were investigated using Response Surface Methodology (RSM) based on a Central Composite Design (CCD). The optimum conditions of size sorting efficiency were revolved speed of 8.35 rpm, sorting angle of 5.05 degree and feed rate of 26.59 kg/h. These provided the size sorting efficiency of 75.15% with high correlating coefficient (R2 = 97.65). This indicated that the data predicted with Response Surface Methodology was good agreement and adequacy of models.

1. Introduction

The coffee consumption in Thailand continuously increases, leading to increase the demand of coffee production. The green coffee bean (GCB) is the important form which is used for coffee processing to coffee product. There are many steps to produce the GCB. The GCB size grading is a necessary step because the size directly effects on the selling price; the price of GCB with large size was higher than that of GCB with small size [1]. It also effects the odor and taste properties of GCB [2]. Moreover, each size of GCB is used for producing in different coffee product. The GCB with small size is commonly processed into powder coffee while the GCB with large size is popularly roasted or sold as coffee bean. Normally, the size of GCB can be divided into four groups according to the Thai agricultural standard [3] such as extra (Ø ≥ 7.1 mm), large (6.3 ≤ Ø ≤ 7), medium (5.6 ≤ Ø ≤ 6.2) and small (Ø ≤ 5.5).

Nowadays, GCB is sorted by size sorting machine using the sieve with different hole size; all sieves were moved along length direction. This is higher efficiency and shorter time when comparing with the worker. However, the size sorting machine was still low efficiency because the GCB is moved in the same direction with the sieve, leading to low distribution of GCB. This provided a lot of GCB stuck in the sieve, leading to low efficiency for size sorting of GCB. One of the methods that can help the distribution of GCB to be higher by using sieve moved along width direction. The sieve is perpendicularly moved with GCB. This method causes the GCB to disperse and helps to reduce the amount of GCB stuck in the sieve. The efficiency of GCB size sorting machine would be higher.
Therefore, the size sorting machine with revolved sieve was designed and created for GCB size sorting. Moreover, the increase of efficiency in GCB size sorting machine can be also done by adjusting the important factors such as sorting angle, revolved speed and feed rate. Preetha et al. [4] mentioned that the sorting angle and revolved speed were important factors which affected the performance of rotary drum grader for tomato. Karthik et al. [5] reported that the increase of feed rate provided the decrease of efficiency in the onion grader with manual oscillation system. However, the optimal condition for applying the GCB size sorting using size sorting machine with revolved sieve which depended on sorting angle, revolved speed and feed rate are no report. Therefore, the objective of this research is to find the optimum conditions in the GCB size sorting process using size sorting machine with revolved sieve by Response Surface Methodology.

2. Materials and methods

2.1. Materials

GCB (Robusta variety) with moisture content of 13% wet basis (w.b.) was obtained from the Small and Medium Enterprises (SMEs) in Chumphon province. It was used as the sample in this study. Before testing, the Robusta GCB was sorted into four size by standard manual sieve of Chumphon Plant Research Center, Chumphon province, Thailand. Each size of Robusta GCB was identified by spraying with different color such as white (extra size), red (large size), blue (medium size) and green (small size) as shown in Figure 1. After that, the sprayed Robusta GCB was dried in the shade to a moisture content of 13% (w.b.) and sorted by standard manual sieve again for checking size.

![GCB size with different colors.](image)

**Figure 1.** GCB size with different colors.

2.2. Experiment for sorting process

Figure 2 showed the diagram of size sorting machine with revolved sieve. It mainly comprise of a continuously cylindrical sieve with three hold sizes (5, 6 and 7 mm) which was driven by motor 1, brush system was installed at the top of revolved sieve for cleaning the sieve during sorting processes, feeding hopper with the capacity of 5 kg with controlling the feed rate by motor 2 and four outlets for GCB. The sorting angle of revolved sieve was adjusted by sorting angle adjustment. For testing, the sorting angle, revolved speed and feed rate were varied following the experimental design shown in
Table 2. The well-mixed size of GCB was fed into the revolved sieve and the associated feeding time was measured. When no Robusta GCB was observed in the rotating sieve, the measured feeding time was stop. The Robusta GCB from each outlet were removed to analyze. The correctly and incorrectly classified GCB were sorted and weighed in each outlet.

Figure 2. Diagram of size sorting machine with revolved sieve.

2.3. Experimental design
Table 1 showed the experimental design for size sorting efficiency. Three main parameters were studied sorting angle, revolved speed and feed rate by Central Composite Design (CCD) using Minitab version 18 software. The total number of the experiment was 20 runs for optimization process [6]. RSM is a collection of statistical and mathematical techniques that is useful for developing empirical model building, optimizing processes parameter and it can also be used to find the interaction of several affecting factors.

Table 1. Experiment design for size sorting efficiency.

| Variable descriptions | Code | Unit   | Levels     |
|-----------------------|------|--------|------------|
|                       |      |        | Low (-1)   | High (+1) |
| Sorting angle         | A    | Degree | 2          | 6         |
| Revolved speed        | B    | Rpm    | 6          | 10        |
| Feed rate             | C    | kg/h   | 30         | 40        |
2.4. Analysis of size sorting efficiency.
Size sorting efficiency [7] was defined by applying the equation proposed as shown in Eq. (1)

\[
E_w = \frac{\sum P_{gi} W_i G_i}{Q P_i}
\]

Where,
\( E_w \) is Size sorting efficiency,
\( P_{gi} \) is fraction of GCB size i to total GCB dropping into receiving outlet size i
\( W_i \) is fraction of GCB size i at the beginning of sizing to total GCB at the beginning of sizing
\( G_i \) outflow rate of GCB size i (kg/h),
\( G_i \) is outflow rate of GCB size i (kg/h),
\( P_i \) is fraction of size i total GCB at the beginning of sizing,
\( Q \) is feed rate (kg/h).

2.5. Analysis of statistical.
Non-linear regression analysis [8] was carried out from data collected by Central Composite Design for the response (Size sorting efficiency), sorting angle, revolved speed and feed rate. The efficiency of machine was fitted as a second-order polynomial equation which included the effect of linear terms, square terms and interaction terms on the response. The response value was represented by a polynomial quadratic equation as shown in Eq. (2)

\[
Y = \beta_0 \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_i x_i^2 + \sum_{i<j}^{k} \beta_{ij} x_i x_j
\]

where the response is \( Y \), the linear terms, square terms and interaction terms is \( x_1, x_2, x_k, x_1^2, x_2^2, x_k^2, x_1x_2, x_2x_3, x_{k-1}x_k \), respectively.

3. Results and discussion
3.1. Optimization of size sorting efficiency.
The results of experimental design for size sorting efficiency shows in Table 2. The optimization of size sorting efficiency of 5.05 degree, 8.35 rpm and 26.59 kg/h for sorting angle, revolved speed and feed rate, respectively while the size sorting efficiency was an optimum point of 75.15%. The fit of model was checked by determination coefficient (R^2). It was about 0.9765 indicating that 97.65% of total variability in size sorting efficiency for size sorting machine. This showed that the variability can able to good explain by the model. The value of adjusted determination coefficient of 96.56, which indicated that it advocated for a good significance of the model as well. The Lack-of-Fit was insignificant but the model F-value of 89.87 implied that the model was significant (P-value less than 0.05). These identified a suitability of model as shown in Table 3. In the terms of \( A, B, C, A^2 \) and \( B^2 \) were significant model terms but in the term of \( C^2 \) was insignificant model term. The equation of optimal condition for size sorting efficiency as a code factors shown in Eq. 3.

\[
Y = 3.5 + 14.308A + 13.62B - 1.11C - 1.4123A^2 - 0.8170B^2 + 0.0116C^2
\]

Which \( Y \) = Size sorting efficiency (%)
\( A \) = Sorting angle (degree)
\( B \) = Revolved speed (rpm)
\( C \) = Feed rate (kg/h)
Table 2. The experiment design for size sorting efficiency.

| Run order | A (degree) | B (rpm) | C (kg/h) | Response $E_w$ (%) |
|-----------|------------|---------|----------|--------------------|
| 1         | 2          | 6       | 30       | 54.66              |
| 2         | 6          | 6       | 30       | 68.50              |
| 3         | 2          | 10      | 30       | 58.24              |
| 4         | 6          | 10      | 30       | 67.34              |
| 5         | 2          | 6       | 40       | 53.28              |
| 6         | 6          | 6       | 40       | 64.27              |
| 7         | 2          | 10      | 40       | 57.14              |
| 8         | 6          | 10      | 40       | 66.29              |
| 9         | 0.64       | 8       | 35       | 42.87              |
| 10        | 7.36       | 8       | 35       | 66.14              |
| 11        | 4          | 4.64    | 35       | 59.24              |
| 12        | 4          | 11.36   | 35       | 63.24              |
| 13        | 4          | 8       | 26.59    | 75.10              |
| 14        | 4          | 8       | 43.41    | 67.50              |
| 15        | 4          | 8       | 35       | 69.81              |
| 16        | 4          | 8       | 35       | 69.04              |
| 17        | 4          | 8       | 35       | 69.27              |
| 18        | 4          | 8       | 35       | 70.94              |
| 19        | 4          | 8       | 35       | 70.87              |
| 20        | 4          | 8       | 35       | 70.59              |

Table 3. ANOVA test for model regression of size sorting efficiency.

| Source    | Df | Adj SS  | Adj MS  | F-value | $p$      |
|-----------|----|---------|---------|---------|----------|
| Model     | 6  | 1126.49 | 187.75  | 89.87   | 0.000    |
| Linear    | 3  | 542.37  | 180.79  | 86.54   | 0.000    |
| A         | 1  | 494.94  | 494.94  | 236.92  | 0.000    |
| B         | 1  | 16.53   | 16.53   | 7.92    | 0.015    |
| C         | 1  | 30.90   | 30.90   | 14.79   | 0.002    |
| Square    | 3  | 584.11  | 194.70  | 93.20   | 0.000    |
| A*A       | 1  | 459.89  | 459.89  | 220.14  | 0.000    |
| B*B       | 1  | 153.90  | 153.90  | 73.67   | 0.000    |
| C*C       | 1  | 1.20    | 1.20    | 0.58    | 0.462    |
| Error     | 13 | 27.16   | 2.09    |         |          |
| Lack-of-fit| 8 | 23.72   | 2.96    | 4.32    | 0.062    |
| Pure Error| 5  | 3.43    | 0.68    |         |          |
| Total     | 19 | 1153.65 |         |         |          |

$R^2 = 97.65\%$, Adj $R^2 = 96.56\%$, Pred $R^2 = 92.07\%$
The 3D Response Surface Plots for size sorting efficiency against two independent variables were plotted to show the effects of the independent variables and combined effects of each independent variable upon the response variable shown in Figure 3-5. Figure 3 showed the size sorting efficiency between sorting angle and revolved speed with holding the feed rate of 35 kg/h. When sorting angle and revolved speed were increased from 2 to 4 degree and 6 to 8 rpm, respectively, the size sorting efficiency was increased because the GCBs were less pressed, leading to faster movement of GCB and resulting in the decrease of sorting time [9, 10]. However, the size sorting efficiency was decreased when sorting angle and revolved speed were increased from 4 to 6 degree and 8 to 10 rpm, respectively. Although the sorting time was decreased, a lot of GCB was dropped to incorrect category because of excess movement speed, leading to more incorrectly classified GCB.

![Figure 3. Size sorting efficiency against sorting angle and revolved speed.](image1.png)

![Figure 4. Size sorting efficiency against sorting angle and feed rate.](image2.png)

The size sorting efficiency between sorting angle and feed rate with holding revolved speed of 8 rpm was shown in Figure 4 while the size sorting efficiency between revolved speed and feed rate with holding sorting angle of 4 degree was shown in Figure 5. These results showed that the feed rate affected the size sorting efficiency in the different pattern when comparing with revolved speed and sorting angle. The size sorting efficiency was decreased with increasing the feed rate. The increase of
feed rate caused the lower distribution of GCB because of increased GCB, leading to longer sorting time for size sorting.

![Figure 5](image1.png)

**Figure 5.** Size sorting efficiency against revolved speed and feed rate.

![Figure 6](image2.png)

**Figure 6.** Predicted values against observed values for size sorting efficiency.

3.2. Model validation

Figure 6 showed the correlation between the predicted and observed values to verify the accuracy of the model. It was found that the ranges of size sorting efficiency were 42.87-75.10% for the experimental values and 44.11-73.49% for the predicted value within the range of 0.64-7.36 degrees for sorting angle, 4.64-11.36 rpm for revolved speed and 26.59-43.41 for feed rate. They were plotted approximately along a straight line which provided the determination coefficient of 0.97. This implied that prediction of experimental data is quiet satisfactory and it can give a convincingly good estimate of response for the size sorting process in the range studied.

4. Conclusion

The size sorting efficiency of size sorting machine with revolved sieve can increase by using Response Surface Methodology based on Central Composite Design. Through the use of RSM, the feed rate has
the least significant effect on size sorting efficiency while the sorting angle and the revolved speed were found to greatly affect the size sorting efficiency. Moreover, the optimal condition of size sorting machine was determined. The size sorting efficiency of 75.15% was obtained at revolved speed of 8.35 rpm, sorting angle of 5.05 degree and feed rate of 26.59 kg/h. The experimental values obtained for size sorting machine with revolved sieve were found close to the predicted values from the model.

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