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Modeling of an Octagonal Shape Pilot Trommelfor Raw Cashew Nuts Calibration

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Abstract:
The first step in cashew nuts shelling process is to size them by width class. Trommels are fast way to sort the products by size. This paper proposes modeling and testing of a pilot trommel, designed with an octagonal shape, which will be used for sizing cashew raw nuts. Experiments were performed with four parameters namely mix compositions with undersized nuts, feed rate, rotational speed, and trommel inclination. The trommel's length was divided into three sections of length twice the side of the octagon. The study showed that the mix compositions with undersized nuts has low influence on the sorting efficiency. It was observed that the feed rate, the rotational speed, and the inclination individually influence the performance of the calibrator and their combination showed iso-level efficiency curves with parabolic forms. The quadratic model, obtained by using DESING EXPERT software, were significant for modeling the pilot trommel with 250 mm as length of the side. The optimal operating point of the model corresponds to a feed rate of 360 kg/h, a speed of 7.24 rpm and an inclination of 0.25°. This point achieves an average efficiency of 99.9%. A screening length equivalent to four times the side measurement of the octagon is sufficient to optimize the efficiency.

***Key words**: Cashew nuts; trommel; calibrator; efficiency; modeling; optimization*

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I. INTRODUCTION

Cashew nuts are the fruits of cashew tree (*Anacardium Occidentale* L.) native to Brazil. It is cultivated in the humid tropical zones of Latin America, Africa, and Asia. The world production of cashew raw nuts exceeds 3.28 million tons. The nut contains a kernel, rich in vitamin B1 and protein, used in the food industry as a cocktail treat or in cooked dishes and pastry[1,2]. The masses of raw nuts vary between 2 and 14 g, while kernels have their masses between 0.5 and 4 g. The dimensions of the nuts, taken with respect to the main axis (figure 1), vary between 18 and 42 mm in length, between 14 and 34 mm in width, and between 12 to 23 mm for thickness[3,4].

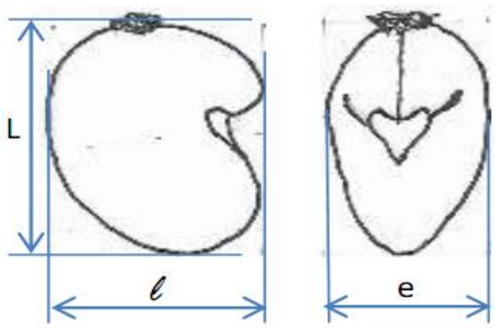


Figure 1: Main dimensions of a cashew raw nut: L = Length; ℓ=width; e= thickness

For processing, the dried raw nuts are first calibrated by size and then steamed before shelling. Grading is a practice of cashew industries that aims to classify nuts according to defined widths with a rotating drum, called trommel[5,6,7]. The trommels are equipment whose main part is a cylindrical or polygonal shell rotating around a horizontal axis or slightly inclined with respect to the horizontal. The sizing technique consists in making pass

through holes the undersized particles or grains of dimensions lower than a defined value. The sorting is performed when the particle meets a free hole in the shell and is correctly oriented[8,9].
The sorter efficiency is the ratio between the output fraction of undersized particles and the initially fraction. Models of the trommel efficiency are made with their inclination angles, rotational speeds, and material flow rates[9,10,11,12].
To test trommels efficiency for sorting tomato seeds (*Lycopersicon esculentum*), Kopral et al.[13] performed a preliminary sizing and then composed a sample of single mixture with three grain sizes.
The rotational speed and the particles flow rate dictate the flow regime of the particles in the cross section of the drum: for sizing the particles, the trommel must be operated in the avalanching mode with a filling rate less than 10 %[14,15]. The avalanching flow regime corresponds to low rotational speeds. The trommel inclination from the horizontal axis is usually between 2° and 6°[11,16]. Some authors reported higher inclinations like 8° for Kopral et al.[13] and 12° for Bellocq et al.[17].
Our objective is to model efficiency of a rotating octagonal drum that can be used for sizing raw cashew nuts with the parameters of rotational speed, feed rate and axis inclination.

II. MATERIAL AND METHODS

II.1. Plant material

Raw cashew nuts from Côte d'Ivoire (first producer in the word) were used at a moisture content between 8.5 and 9.1 % (average of 8.9 %). A special calibrator was used for cleaning and preliminary sizing of cashew nuts. Calibrated nuts were grouped in three batches: the small nuts coming out at 17.5 and 19 mm, the medium ones coming out at 20 and 21 mm and the large ones coming out at 22, 23 and 24 mm. The smallest and the largest nuts were used to make up four 40 kg samples[13] in which the small nuts are mixed in the proportions of 10%, 25%, 50% and 80%.

II.2. Technical equipment

The pilot calibrator (figure 2) was made with octagonal drum of 250 mm of side and single bore diameter set at 20 mm. The fraction of screen aera occupied by bores was 47.75 % and the length of the drum was 1 500 mm. The length was divided into three parts of 500 mm to be able to follow the evolution of the efficiency as a function of the distance traveled by the particles. Each part corresponds to a length equivalent to twice the length on the side of the octagon (2C). This division corresponds to the three outputs of the small cashew nuts of the calibrator while the large nuts come out through the fourth frontal output. The trommel is fixed on a rigid frame of length 2,300 mm; thus, with a wedge of calculated height one can adjust the drum inclination. A bucket conveyor feeds the trommel from a hopper whose opening is adjustable to give constant flow. A geared motor rotating at 33 rpm is used with sets of chain sprockets to vary the rotational speeds.

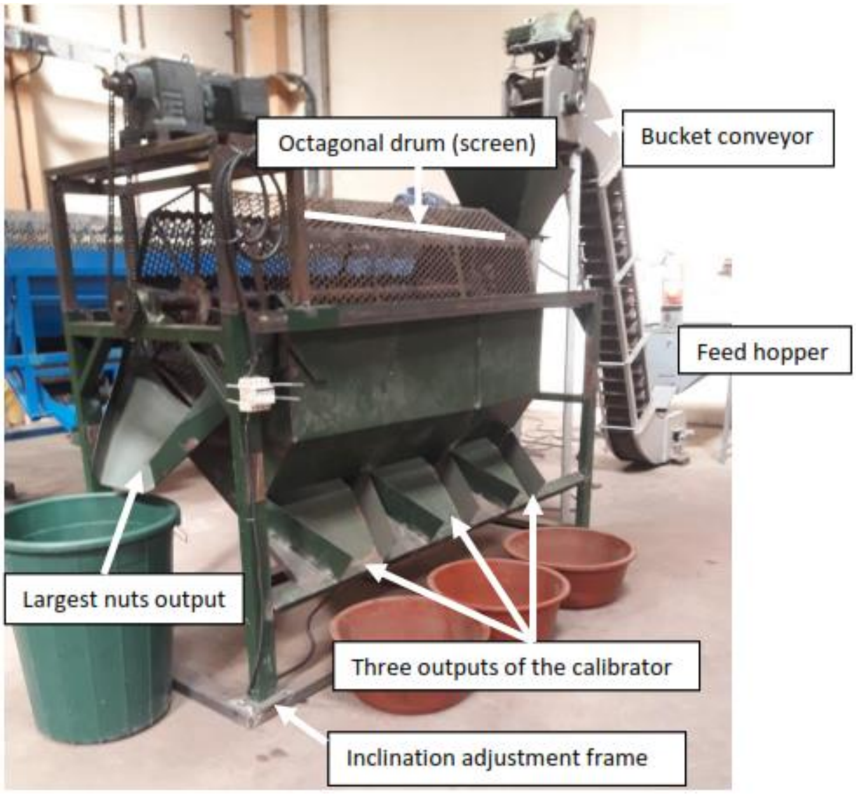


Figure 2: Pilot calibrator of raw cashew nuts.

II.3. Assessment of efficiency

For discrete models, consider the initial mass of product to be output ($m_{initial}$) and the mass of product output (m_{output}), the trommel efficiency is given by the ratio (1)[16]:

$$\boldsymbol{E = (m_{output}/m_{initial}) * 100} \quad (1)$$

The continuous model gives the efficiency as function of the residence time or the distance traveled by the particles in the trommel [8,10,18]. In a trommel with a screen length L, the efficiency at distance x is given by equation 2:

$$\boldsymbol{E(x) = 1 - e^{-\lambda x}} \quad (2)$$

Where $0 \leq x \leq L$ and λ is the pass factor.

The pass factor is difficult to evaluate because of several parameters related to the equipment, the material to be processed and the operating conditions.

II.4. Experiments set up

For the selection of drum inclination, screening tests were done with inclinations ranging from 0° to 2°. That allowed to find the efficiency drops drastically between 1.5° and 2°. Five values of inclination (0.075°; 0.25°; 0.5°; 1° and 1.5°) have been thus retained.

For the selection of rotational speeds, chain sprocket set allows for the selection of five speeds of 4 rpm, 5.69 rpm, 6.45 rpm, 11 rpm and 15.47 rpm.

For the selection of feeding rates, opening levels of the feeding hopper were set to 300 kg/h, 400 kg/h and 600 kg/h. The capacity of feeding time gives maximum variations of ± 6 kg/h.

At each test the masses of small nut leaving at the three outputs of calibrator were taken. Knowing the initial mass, the ratios and their cumulations were computed to find the sorting efficiency according to the length of the drum. Thus, by designating by C the length of the side of the octagon, the three sections correspond to drums of respective lengths of 2C, 4C and 6C.

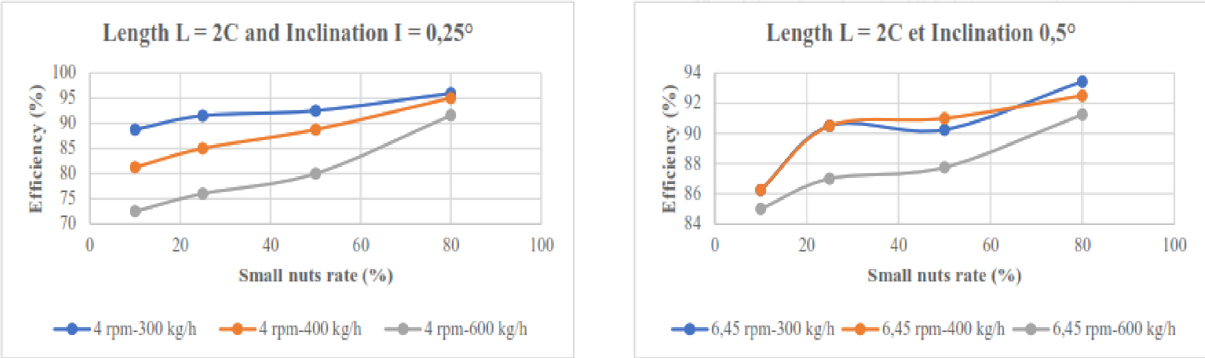
II.5. Statistical analysis

The analysis of individual effects of each parameter was done with the EXCEL software. The modeling of efficiency as a function of the three parameters was done with DESIGN-EXPERT software (DESIGN-EXPERT 12, trial version) which allows to visualize the model's contour lines.

III. RESULTS AND DISCUSSIONS

III.1. Effects of mixture compositions and drum length on calibrator efficiency

For a short drum (L = 2C) as shown in both examples of figure 3, the efficiency increases when the rate of small nuts increases. Sorting is more important at low speed with a high rate of small nuts but does not exceed 95% in efficiency.

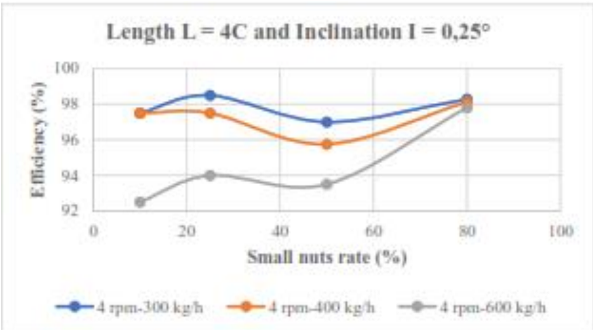


a: Efficiency for 2C length and 0,25° inclination

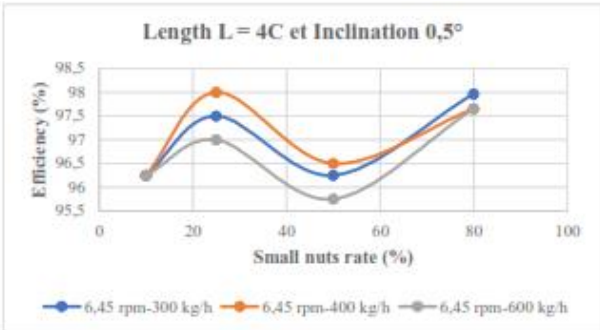
b: Efficiency for 2C length and 0,5° inclination

Figure 3: Efficiency of calibrator for a short drum

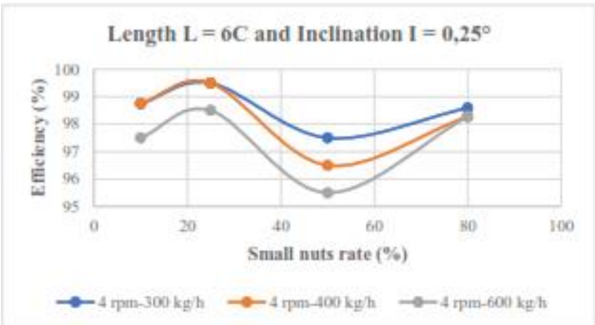
With a long drum, L = 4C and L = 6C, the efficiency is over 95 % and increases with the length. The efficiency curves have sinusoidal gaits with relative maximum values for a composition with 25% of small nuts and minimum values for a composition with 50%. The examples of curves in figure 4 illustrate that for moderated feed rates the difference between the two extreme values of efficiency does not exceed 5%.



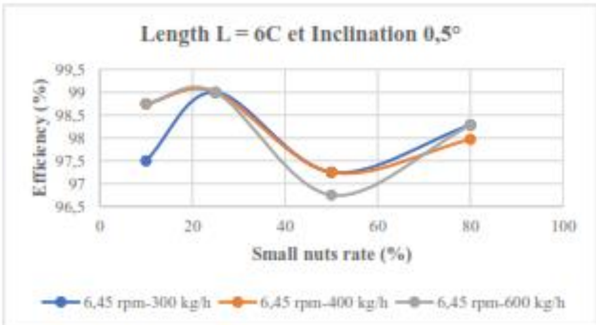
a: Efficiency for 4C length and 0,25° inclination



b: Efficiency for 4C length and 0,5° inclination



c: Efficiency for 6C length and 0,25° inclination



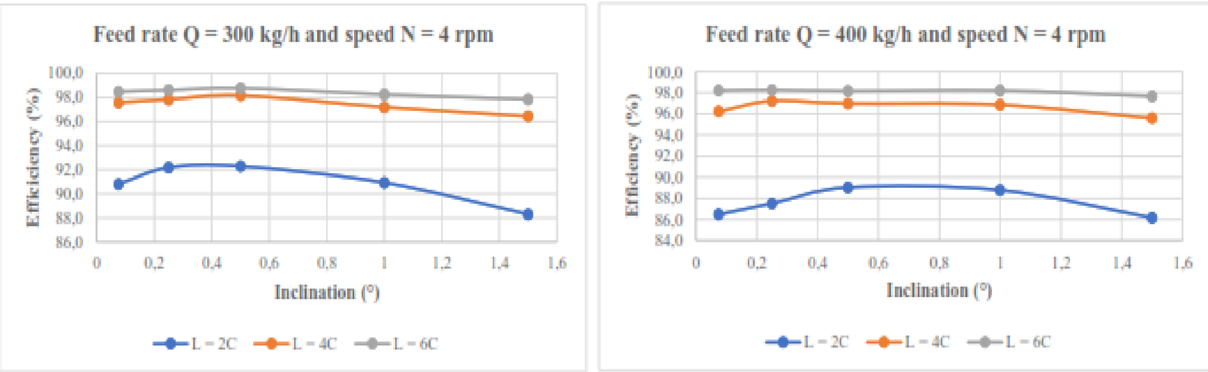
d: Efficiency for 6C length and 0,5° inclination

Figure 4: efficiency for a long drum

During calibration the instantaneous composition of the mixture varies, however the variation in efficiency remains small. One can replace the results of the four compositions by their average.

III.2. Effects of the drum inclination on calibrator efficiency

The curves in figure 5 show that the efficiency increases between 0° and 0.25° and then decreases for inclination above 0.5°. These examples denote parabolic functions whose maximum is between 0.25° and 0.5°. This trend is the same as Chen et al.[16] founded in the case of a hexagonal drum. Their study founded that the efficiency increased between 2° and 5° and then decreased.



a: Efficiency at (300 kg/h; 4 rpm) **b:** Efficiency at (400 kg/h; 4 rpm)

Figure 5: Examples of efficiency curves as a function of drum inclination.

The figures 4 and 5 show that efficiency increases with the length of the drum. The optimal length is of the order of 4C which gives less than 2% difference for longer lengths. It is found that the efficiency decreases when the material flow is increased. This trend is also found by Chen et al.[16] and Hurburgh et al.[19].

III.3. Efficiency modeling of the calibrator drum

The parabolic trends for the effects of inclination and rotational speed justify the choice of the quadratic models proposed by DESIGN-EXPERT. The respective F-values of 87.2; 38.5 and 18.3 with p-value < 0.0001, for the three sections indicate that the models are significant and can be used for navigation in the parameter value spaces.

III.3.1. Combined effects of rotational speed and inclination

The parabolic efficiency level curves shown in figure 6, indicate that the speed is increased to an optimum value the inclination can be increased to its optimum value. Any increase in speed beyond that requires a decrease in inclination to maintain the same efficiency level. These parabolic curves justify both types of results for a fixed inclination: Sucher[20] found that efficiency increased with speed while Bellocq et al.[17] and Lau et al.[21] achieved a contrary trend.

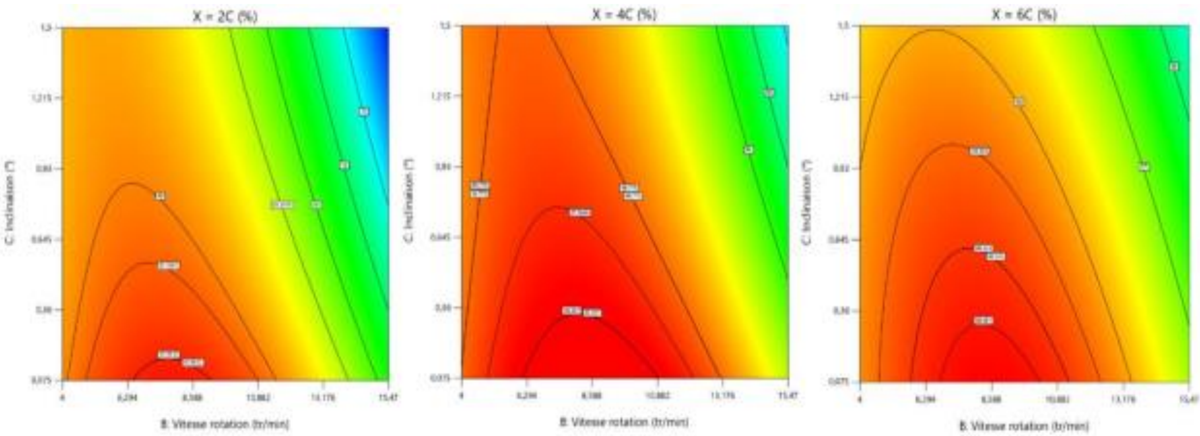


Figure 6: Efficiency as function of rotational speed and inclination

III.3.2. Combined effects of flow rate and inclination

The decreasing linear trend of the curves, as shown in the figure 7, indicates that when the material flow rate increases the efficiency decreases. The decrease in efficiency due to an increase of the material flow rate can be compensated by decrease of the inclination.

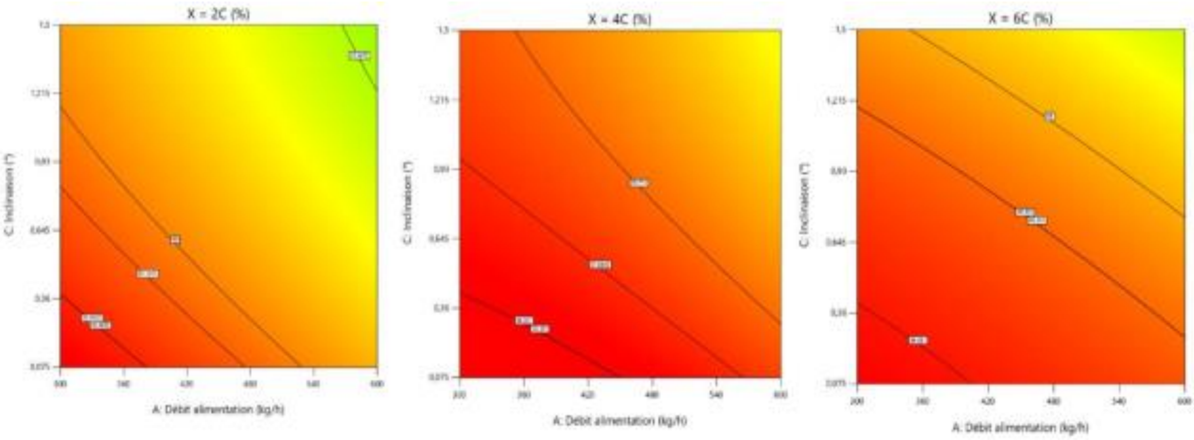


Figure 7: Efficiency as a function of flow rate and inclination (N = 7.24 rpm)

III.3.3. Combined effects of rotational speed and flow rate

The parabolic pattern of the efficiency level curves (Figure 8) indicates that the rotational speed and flow rate can be adjusted to their optimal values for a given efficiency. Any increase in speed or flow beyond the optimal values leads to a decrease in efficiency, which must be compensated by properly varying the other parameter. This is consistent with Glaub and his co-authors[10] that the loss of efficiency due to high flow rate can be partially compensated by an increase in speed.

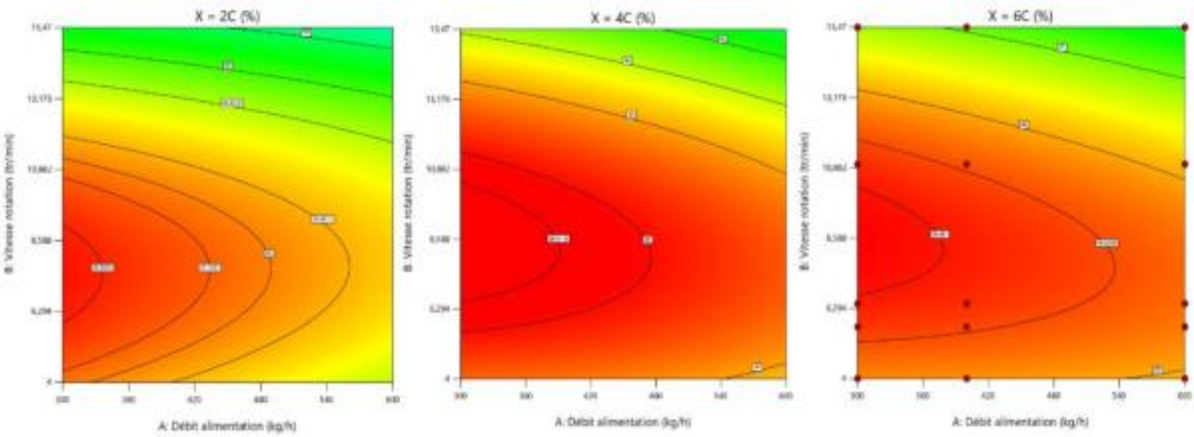


Figure 8: Efficiency as function of rotational speed and flow rate

III.3.4. Efficiency model for a short drum with a length of 2C

For this section, navigating the response space with the software (figure 9) shows that the optimal flow rate is between 300 and 320 kg/h, the optimum rotational speed is between 6 and 7 rpm, and the inclination can be chosen between 0.16° and 0.35°.

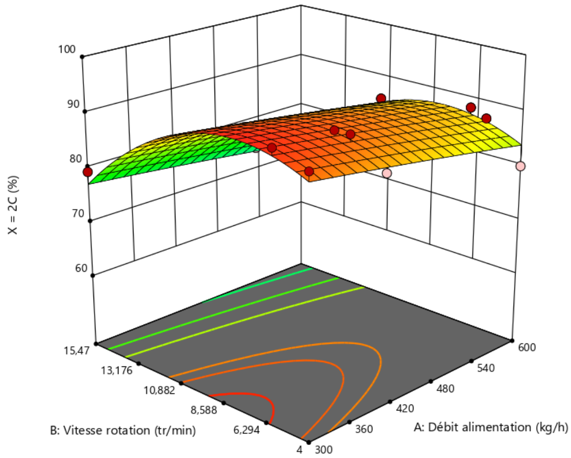


Figure 9: Response surface for a 2C long drum at 0.25° inclination

The software indicates the efficiency ranges from 61.7% to 94.4% with the following equation.

$$\boldsymbol{E(X = 2C) = 84.55 - 0.017Q_m + 3.931N + 1.369I - 0.915NI - 0.258N^2} \quad (3)$$

All three parameters influence the efficiency, but the rotational speed plays a dominant role as it appears squared and in combination with the other parameters.

III.3.5. Efficiency model for a medium drum with a length of 4C

At figure 10, the model shows a variation in efficiency between 84.6% and 98.5% with the optimal flow rate between 360 and 380 kg/h. The optimum rotational speed can be chosen between 7 and 8 rpm, and the inclination is between 0.20° and 0.25°. The software indicates that the efficiency equation for a drum with a length of 4C is:

$$\boldsymbol{E(X = 4C) = 89.7 + 0.008Q_m + 2.036N + 1.097I - 0.001Q_mN - 0.353NI - 0.105N^2} \quad (4)$$

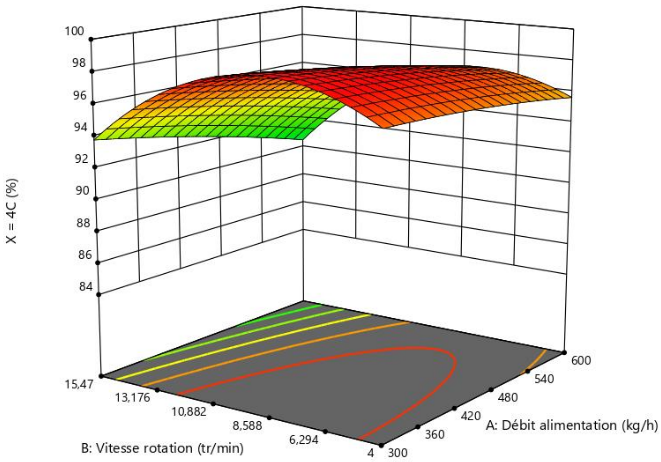


Figure 10: Response surface for a 4C long drum at 0.25° inclination

III.3.6. Efficiency model for a long drum with a length of 6C

At figure 11, the model shows a variation in efficiency between 94.1% and 99.5% when the optimal inclination is between 0.20° and 0.25°. The optimal flow rate is between 360 and 400 kg/h and the optimum rotational speed can be chosen between 7 and 8.5 rpm. For the long drum with a 6C length, the software shows that the model equation is:

$$\boldsymbol{E(X = 6C) = 95.9 + 0.002Q_m + 0.636N + 0.666I - 0.087NI - 0.032N^2} \quad (5)$$

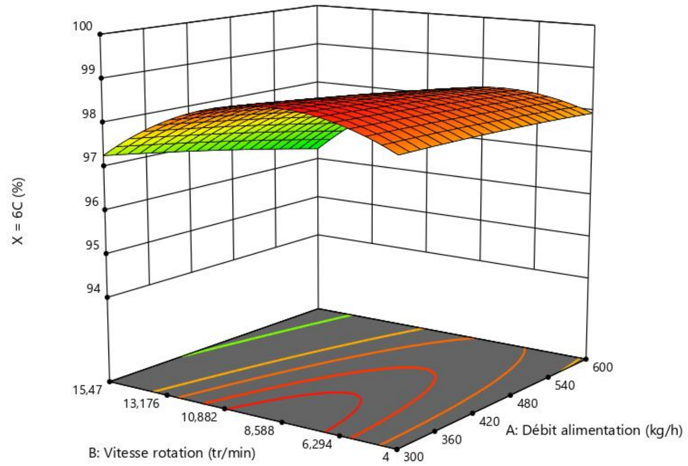


Figure 11: Response surface for a 6C long drum at 0.25° inclination

III.4. Multi-objective optimization of the calibrator drum

Finding solutions that optimize the three models simultaneously is possible with the software as it is shown in figure 12. The point of convergence of the three models is founded by successively adjusting the three curves. The software gives the prediction point with a 95 % confidence level.

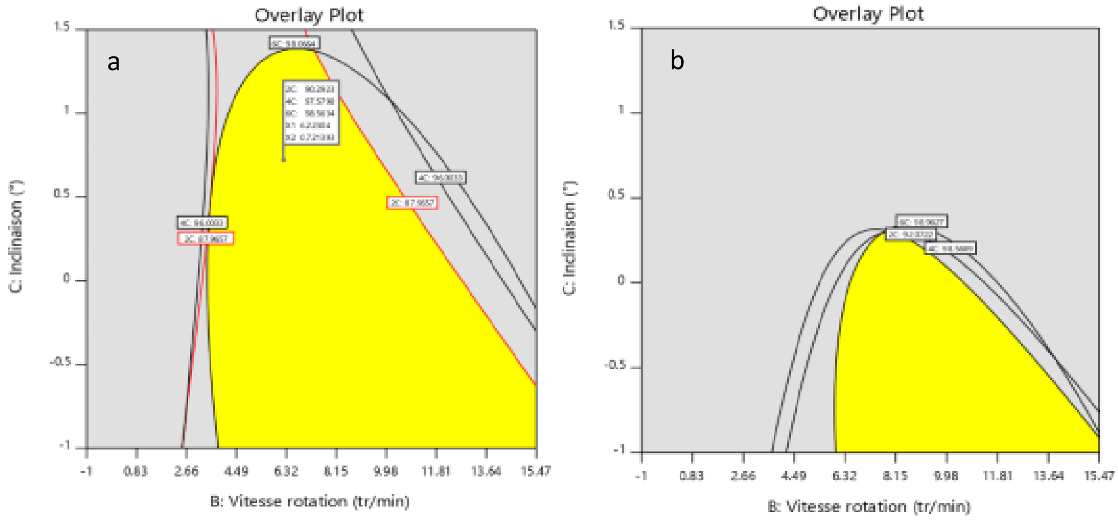


Figure 12: Optimization of the calibration by the response surface method: a) initial proposal; b) optimized proposal

The prediction point found by this method indicates: a flow rate of 360 kg/h; a rotational speed of 7.24 rpm and an optimal inclination of 0.25°. One can observe a strong increase in efficiency on the first section (X = 2C) to reach average efficiencies (SD) of 93.6% (± 1.9%). The efficiency reaches an average of 98.5% (± 1.0%) with the contribution of the second section (X = 4C). The third section (X = 6C) achieves an average efficiency of 99.0% (± 0.5%). This result shows that the optimal length of an octagonal drum for sorting raw cashew nuts is 4C. The ratio of length to equivalent diameter is there for 1.57 which is smaller than 2 to 6 range reported by Wheeler and co-authors[11] for a cylindrical drum.

IV. CONCLUSION

The tests were performed with a raw cashew nuts calibrator, whose drum has an octagonal shape of 250 mm on each side.

(i) The richness of small nuts in the mixture has little influence on sorting efficiency; however, there is a slight decrease in efficiency when the mixture is balanced with 50% small nuts.

(ii) The parabolic efficiency iso-level curves, observed from the quadratic model, reflect the combined influences of the three variables (flow rate, inclination, and rotational speed), rotational speed has a preponderance.

(iii) A screen length of four times the octagon side measurement or 1.57 times the equivalent diameter, is economically and technically sufficient to optimize efficiency.
(iv) The optimizing operating point of the model correspond to a flow rate of 360 kg/h, an inclination of 0.25°, and a rotational speed of 7.24 rpm. This model point achieves an average efficiency of 99.9 %.

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