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Article in IOP Conference Series Materials Science and Engineering · May 2020

DOI: 10.1088/1757-899X/847/1/012085

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Optimisation of Mechanical Cassava Peeling System Parameters

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Abstract. This study focused on investigations of effects of mechanical parameters (peeling speed, cutter length) and handling parameter (cassava tuber length) of a cassava peeling machines on the machine output (peeling and recovery efficiencies) with the view of optimizing the parameters. The serious issues of existing techniques of peeling cassava are moderately low peeling and recovery efficiencies because of the irregular shape and size of cassava tubers. The results of the trial of the machine utilizing the cassava tubers revealed that all the parameters have significant effects on the peeling and recovery efficiencies of the machine. The cutter length had a more significant impact on the peeling and recovery efficiencies. Maximum values of 83.5 % and 97.2% for peeling and recovery efficiencies respectively, with an attractive quality of 0.864 were achieved from peeling cassava tuber of 50 mm length with cutter length of 2 mm at a speed of 328 rpm. The investigation's discoveries give the standard machine input parameters which are equipped for improving quality, peeling and recovery efficiencies of a mechanical cassava peeling system.

Keywords: cassava, cutter length, machine, optimum, peeling

1. Introduction

Cassava is presently a significant crop for both local utilization and export promotion. It has been reported to have various advantages, for example, well being, monetary and as methods for accomplishing food availability [1]. Among the most important unit processes involved in cassava processing are peeling, grating, boiling, drying, milling, sieving, extrusion and frying [2]. Cassava peeling is and has always been a major challenge for design engineers engaged in manufacturing machines and equipment for cassava processing [3]. This is because of its unusual shape, dimension, peel thickness, and even the weight of the same variety [4]; [5]. Presently, cassava peeling operation is accomplished using a manual and mechanical technique. As reported by [6], the manual technique comprised the use of a knife that is, tedious and time-consuming. The mechanical approach, however, entails the use of the machinery and equipment in cassava peeling. Generally, the efficiency of a cassava peeler depends on the peeling mechanism, which could be in the form of perforated drums or a blade, peeling speed or the cassava tubers, length, size, volume and of the cassava tuber variety. Some of the recent research work on mechanical cassava peeling techniques, their peeling and recovery efficiencies are as follows; [7] designed a cassava peeling machine with an abrasive drum as the



peeling mechanism. The peeling and recovery efficiencies of the machine were 65% and 95% respectively. The major limitation of this machine is its time consumption. A machine with an external peeling mechanism that produced cassava peeling and recovery efficiencies of 60% and 94%, respectively was developed by [5]. The drawback of this machine was the high losses and grating of cassava tubers. An automated cassava peeler was designed by [8]. The peeling and recovery efficiencies of this machine were 48% and 86% respectively. This machine needed expertise and could not absolutely peel smaller tuber sizes. A peeler that operates based on Lathe machine principle was developed by [9], the machine had a peeling efficiency of 65% and recovery efficiency of 88%. The major limitation of this machine is its higher mechanical damage. [10] developed an automated cassava peeler with knife-edge peeling mechanism. The peeling and recovery efficiencies of the machine were 83% and 58% respectively. The major problem of the machine is it could not peel tiny sizes of tubers and has a significant loss. A double action, self-fed cassava peeling machine with peeling and recovery efficiencies of 80% and 92%, respectively, was developed by [10]. This design had a complex working mechanism, high peel retention and requires hand trimming of tubers and skill operator. Generally, all the shortcomings of these machine centered on the size of peeling mechanism, speed of peeling and the span of the straight portion of a tuber. Hence, to address poor product consistency, relatively low efficiency in peeling and recovery of mechanical peeling system, there is needed to optimize the size of the peeling blade, speed of peeling and the length of the cassava tuber. The objective of this study is to determine the effects of peeling blade, speed of peeling and the length of the cassava tuber on efficiency in peeling and recovery. Also, to established optimum parameters that would yield the best machine output.

2. Methods

2.1 Experimental setup and procedure

A central composite rotatable design of response surface methodology (rsm) made up of three factors varied at five levels was used in this study [11]. The three variables are: peeling speed and cutter size (mechanical variables of the machine) and tuber size (processing variables). The size of the cutter was varied by 0.12, 0.15, 0.2, 0.25 and 0.28cm. The size of the tuber ranged as 1.6, 5, 10 15, 18.4 cm. The peeling speed was varied according to 1232 rpm, 1300 rpm, 1400 rpm, 1500 rpm and 1568 rpm. The test was performed using the template matrix indicated in Table 1. The machine's power switch was on with no load, to test the machine's functionality. The tuber was then fed into the system via the hopper. As the shaft rotates the circular disc at base of the machine creates centrifugal force, which swung the tuber to the cylinder's wall where the tuber's outer skin was peeled. Water was allowed to flow into the machine and this aid in separating the peeled skin from the flesh tubers. The water and peeled skin flowed out of the machine through the lower chute while the flesh cassava tubers are discharged out of the machine through the upper chute

2.2 Testing of the machine

A set of empirical test was conducted to examine the influence of cutter size, peeling speed, and tuber size on peeling and recovery efficiency of a mechanical peeler [2].

2.3. Statistical analysis

Analysis of variance (ANOVA) was performed to estimate the influence of major variables and their potential correlation effect on the responses.

2.4 Machine performance.

The performance of the machine was determined by the peeling and recovery efficiency.

2.4.1 Peeling Efficiency. This is the percentage of the tuber skin peels by the machine to the total mass of the tuber's skin. It was calculated as reported by [2]

$$P_E = \frac{M_{mt}}{M_{mt} + M_{ht}} \times 100 \tag{1}$$

Where P_E is the peeling efficiency (%), M_{mt} is a mass of the tuber skin peel by the machine (kg), M_{ht} is a mass of the peel removed by hand after machine peeling (kg).

2.4.2. Recovery efficiency. This is percentage mass of the flesh tuber after peeling to the total mass of the tuber less the mass of the tuber skin. It was calculated as reported [2]

$$R_E = \frac{M_{ft}}{M_{cb} - M_{sb}} \times 100 \tag{2}$$

Where, R_E is the recovery efficiency (%), M_{ft} is mass of the flesh tuber after peeling (kg), M_{cb} is mass of the cassava tuber (kg), M_{sb} is mass of the tuber skin (kg).

3. Results and discussion

The independent parameters strongly influence cassava peeling process are the cutter size, peeling speed and tuber size. An experiment was conducted to peel cassava tubers by varying and combining the different levels of the independent variables and the responses were measured after each trial. The results obtained are as follows:

3.1. Effects of independent variables on peeling efficiency

The result of the statistical analysis of variance (ANOVA) of the peeling efficiency presented in table 1, showed that the model and all the independent variables were significant with F - value of 41.073 and P-value probability > F less than 0.0500 respectively. The cutter size had a more positive effect on the peeling performance with a coefficient of estimation of 11.7. The size of the tuber had a significant negative effect on the peeling efficiency with a coefficient of estimation of -7.593[13]. The R-square value of 0.9753 was very close to 1 as recommended by [1].

Table 1. Regression analysis of response of peeling efficiency

| Source | Coefficient Estimate | Standard Error | F Value | p-value Prob > F | R-Squared | |
|--------------------|----------------------|----------------|---------|------------------|-----------|-----------------|
| Model | 80.153 | 1.326 | 41.073 | < 0.0001 | 0.9737 | Significant |
| A-Cutter length | 11.701 | 0.880 | 176.699 | < 0.0001 | | |
| B-Speed of Cutting | 7.248 | 0.880 | 67.801 | < 0.0001 | | |
| C-Cassava Length | -7.593 | 0.880 | 74.403 | < 0.0001 | | |
| AB | 2.863 | 1.150 | 6.199 | 0.0320 | | |
| AC | -0.211 | 1.150 | 0.033 | 0.8579 | | |
| BC | 3.336 | 1.150 | 8.414 | 0.0158 | | |
| A ² | -4.899 | 0.856 | 32.695 | 0.0002 | | |
| B ² | -0.165 | 0.856 | 0.037 | 0.8504 | | |
| C ² | -1.993 | 0.856 | 5.413 | 0.0423 | | |
| Lack of Fit | | 5 | 4.264 | 0.0687 | | not significant |

3.1.1. Effects of tuber and cutter sizes on the peeling efficiency. Figures 1 and 2 show the response surface and contour plot for the influence of tuber and cutter lengths and peeling output, respectively. From figure 1, peeling the cassava tubers with cutter size of 2 mm, it was observed that the peeling efficiency remains nearly steady with a value of 84% as the cassava tuber size enlarged from 15 mm to 50 mm, and then decreased significantly to 62% with more increase in the cassava tuber size. This may

be as a result of uneven shape of the cassava tubers which makes it difficult to peel the skin as the length of the cassava increased.

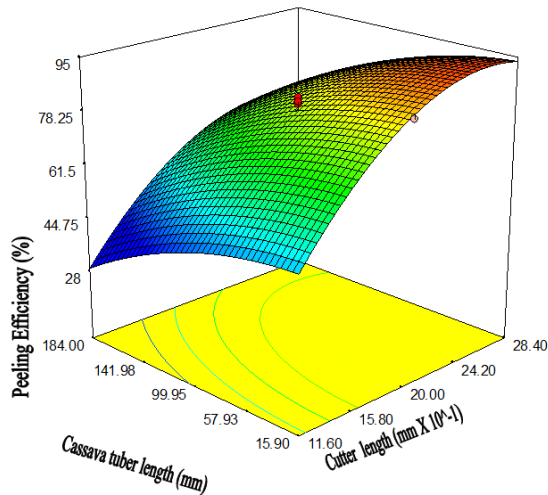


Figure 1. Response Surface for Influence of Tuber Size and Cutter Length on Peeling Efficiency

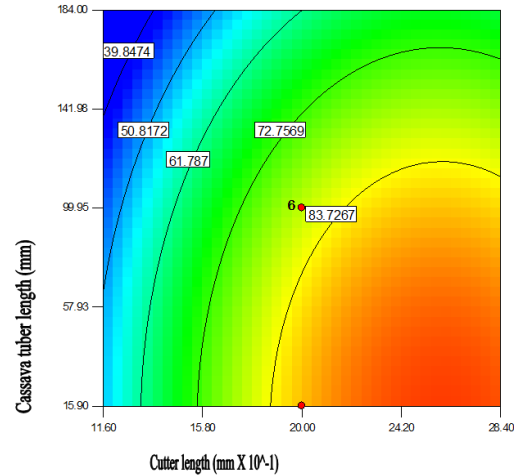


Figure 2. Contour Plot for Influence of Tuber Size and Cutter Length on Peeling Efficiency

3.2. Effects of independent variables of recovery efficiency

The result of the statistical analysis of variance (ANOVA) of the recovery efficiency presented in table 2, showed that the model and all the independent variables were significant with F - value of 48.6 and P-value probability > F less than 0.0500 respectively. The cutter size had a greater effect on the recovery performance, with an approximate coefficient of -7.89, followed by the peeling speed with value of -5.82 and then the tuber size with a value of -4.6. All the three factors had significant negative effect on the recovery efficiency [11]. As suggested by [1], the R- squared value of 0.9777 was very close to 1.

3.2.1. Effects of cassava size and cutter size on recovery efficiency. Figures 3 and 4, respectively, display the response surface and contour plot for the influence of cassava size and cutter size on the recovery performance. The recovery performance improved from 85% to 94% using a cutter size of 2 mm as the size of the cassava increased from 20 mm to 50 mm and then decreased to 70% as the tuber size increased to 187 mm. This could be as results of cutting away some part of the cassava flesh together with the skin layer as a result of uneven shape and size of the tuber. This was agreed with the report from an earlier study [13] in which cassava recovery of a mechanical peeler was found to be low because of loss of more useful flesh. However, the recovery remains almost unchanged with a value of 94% as the cutter size increases from 1.2 mm to 2 mm and then decreases substantially to 73% with a further increase in the cutter size to 2.8 mm. This could be as a result of penetration of the blade deep into the cassava flesh beyond the skin layer, which resulted in cutting away some useful flesh together with the outer layer.

3.3 The optimisation of the machine parameters

The optimisation of the parameters was carried using a numerical technique with the goals of maximizing the efficiencies of peeling and recovery. The result of optimum and the predicted values of the parameters are presented in figures 5 to 10. The desirability (quality) of values of all the dependent and independent variables is presented in figure 11, while the ramp of the optimisation is shown in figure 12. From figure 5, using constant values of cutter and tuber sizes of 207 mm and 50

mm, respectively, the peeling efficiency, increased from 78% to 95% as the speed increases from 266 rpm to 434 rpm. But this high speed had a negative effect on the recovery efficiency, as can be seen in figure 8. Therefore, optimum speed of 328 rpm that best favoured the responses was selected. This gave a predicted value of peeling efficiency of 85.32%.

Table 2. Regression analysis of response of the recovery efficiency

| Source | Coefficient Estimate | Standard Error | F Value | p-value Prob > F | R-Squared | |
|--------------------|----------------------|----------------|---------|------------------|-----------|-----------------|
| Model | 90.089 | 0.888 | 48.616 | < 0.0001 | 0.9777 | Significant |
| A-Cutter length | -7.889 | 0.589 | 178.929 | < 0.0001 | | |
| B-Speed of Cutting | -5.815 | 0.589 | 97.220 | < 0.0001 | | |
| C-Cassava Length | -4.593 | 0.589 | 60.654 | < 0.0001 | | |
| AB | -2.132 | 0.770 | 7.658 | 0.0199 | | |
| AC | -1.087 | 0.770 | 1.991 | 0.1885 | | |
| BC | -0.252 | 0.770 | 0.107 | 0.7499 | | |
| A ² | -4.930 | 0.574 | 73.748 | < 0.0001 | | |
| B ² | -2.699 | 0.574 | 22.108 | 0.0008 | | |
| C ² | 0.169 | 0.574 | 0.087 | 0.7739 | | |
| Lack of Fit | | | 0.735 | 0.6280 | | not significant |

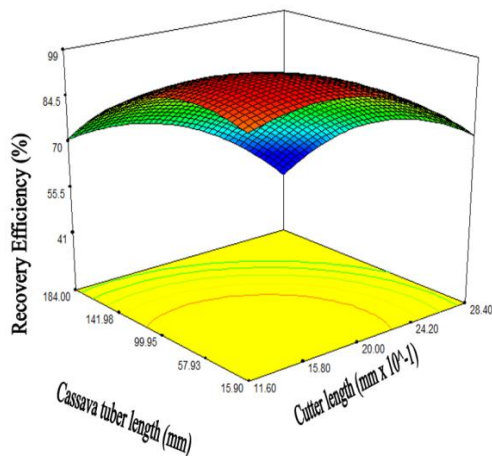


Figure 3. Response Surface for Influence of Tuber Size and Cutter Length on Recovery Efficiency

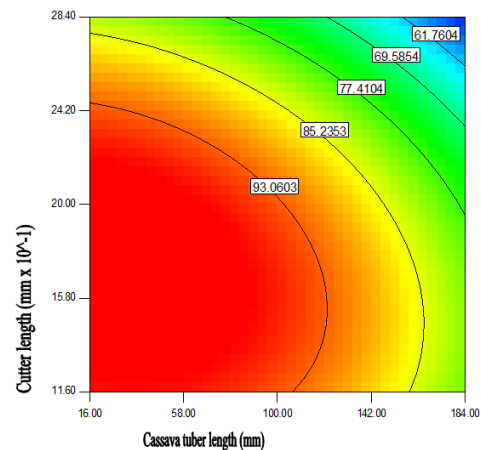


Figure 4. Contour Plot for Influence of Tuber Size and Cutter Length on Recovery Efficiency

With constant values of peeling speed and tuber size of 327.54 rpm and 50 mm, respectively (figure 6), the peeling efficiency, increased from 68% to 93% as the cutter size increases from 1.5 mm to 2.5 mm. However the bigger cutter size had a negative effect on the recovery efficiency, as can be seen in figure 9. This is as a result of increase in depth of penetration of the cutter into the cassava tuber that resulted in peeling off more of the tuber flesh as the cassava skin thickness ranges from 1.5 mm to 2 mm. This agreed with the outcome of an earlier study [1], where segregation of materials by a size reduction system decreased with a decrease in cutter surface area. Therefore the optimum cutter

size of 2.07 mm that best favoured the two responses was selected and this gave a predicted value of peeling efficiency of 85.32%. From figure 7, using constant values of cutter size of 2.07 mm and peeling speed of 327.54 rpm, the peeling efficiency slightly decreased from 87.5% to 85.32% as the tuber size increases from 16 mm to 50 mm and then drastically reduced to 57% with further increased with tuber length to 184 mm. Considering the recovery efficiency, as can be seen in figure 10 an optimum tuber size 50 mm that best favoured the responses was selected. This gave a predicted value of peeling efficiency of 85.32%. With constant values of cutter and tuber sizes of 2.07 mm and 50 mm, respectively as shown in figure 8, the recovery efficiency remains unchanged with a value of 95.92% as the peeling speed increased from 266 rpm to 327.32 rpm and then decreased to 74% with further increase in peeling speed to 434 rpm. Therefore, optimum speed of 327.32 rpm that best favoured the responses was selected. This gave a predicted value of recovery efficiency of 95.92%.

From figure 9, using a constant value of peeling speed and tuber size of 327.54 rpm and 50 mm, respectively, the recovery efficiency remains unchanged with a value of 95.92% as the cutter size increases from 1.5 mm to 2.0 mm, afterward decreased to 85% with further increase in cutter size to 2.5 mm. Value of cutter size below 2 mm had a negative effect on the peeling efficiency as shown in figure 6. This is because the tuber skin thickness ranged from 1.5 to 2 mm. The decreased on the efficiency when peeling with cutter size above 2 mm could be as a result of deep penetration of the cutter into the cassava tuber that resulted in peeling off more of the tuber. Therefore the optimum cutter size of 2.07 mm that best favoured the two responses was selected and this gave a predicted value of peeling efficiency of 95.92%. From figure 10, using constant values of cutter size of 2.07 mm and peeling speed of 327.54 rpm, the recovery efficiency slightly decreased from 97.5% to 94.32% as the tuber size increases from 16 mm to 50 mm and then drastically reduced to 82% with further increased in tuber length to 184 mm. Considering the peeling efficiency (figure 7) an optimum tuber size of 50 mm that best favoured the responses was selected. This gave a predicted value of peeling efficiency of 95.92%. From figure 11, maximizing the efficiencies of peeling and recovery gave a quality value of 0.777 for peeling efficiency, 0.9641 for recovery efficiency and combined quality value of 0.864. The ramp of the optimization shown in figure 12 gave the summary of optimum values of variables; cutter length of 2.07 mm, speed of 328 rpm, and cassava length of 50 mm, which produced peeling efficiency of 85.4% and recovery efficiency of 98.04 %.

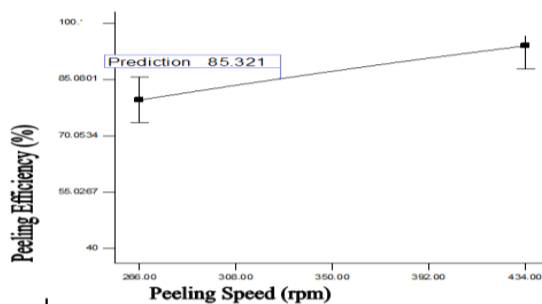


Figure 5.Optimum and Predicted Values of the Peeling Speed with respect to Peeling Efficiency

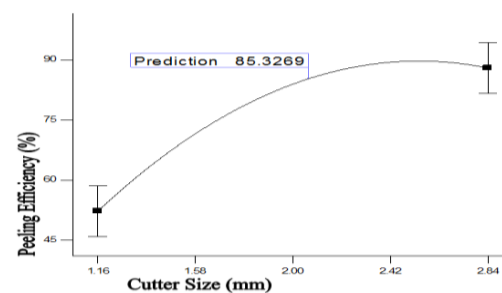


Figure 6.Optimum and Predicted Values of the Cutter Size with respect to Peeling Efficiency

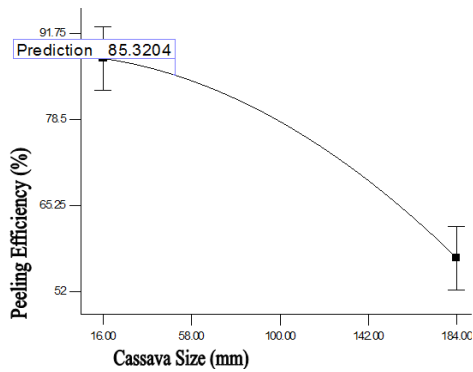


Figure 7. Optimum and Predicted Values of the Cassava Size with respect to Peeling Efficiency

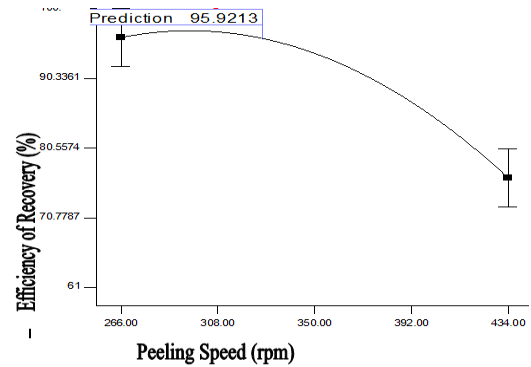


Figure 8. Optimum and Predicted Values of the Peeling Speed with respect to Recovery Efficiency

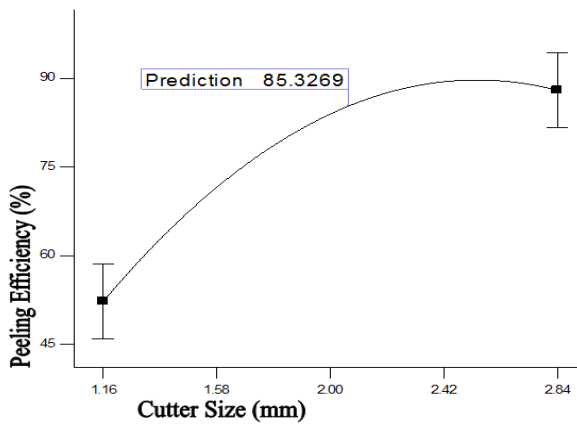


Figure 9. Optimum and Predicted Values of the Cutter Size with respect to Recovery Efficiency

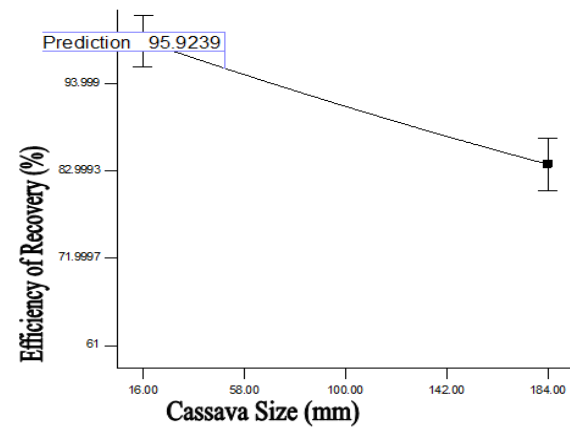


Figure 10. Optimum and Predicted Values of the Cassava Size with respect to Recovery Efficiency

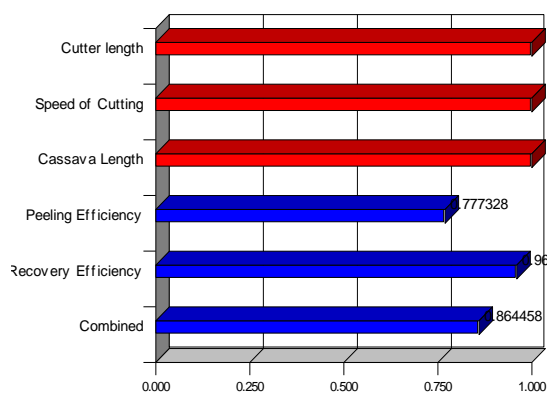


Figure 11. Result of desirability of the individual and combine responses

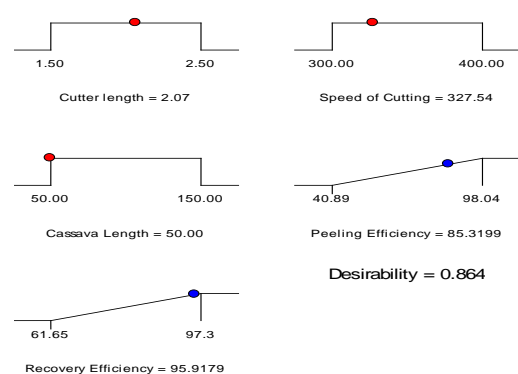


Figure 12. Ramp for optimization of the independent variables

4. Conclusion

The cutter size, peeling speed and tuber size strongly influence the cassava peeling and recovery efficiency. The cutter size had a more positive effect on the recovery efficiency, followed by the

peeling speed while the size of the tuber had a significant negative effect on the peeling efficiency. On the other hand all the three factors had significant negative effect on the recovery efficiency. The optimisation of the parameters gave optimum values of variables; cutter length of 2.07 mm, speed of 328 rpm, and cassava length of 50 mm, which produced peeling efficiency of 85.4% and recovery efficiency of 98.04 %. The result of this investigation give the standard machine input parameters which are equipped for improving quality, peeling and recovery efficiencies of a mechanical cassava peeling system and this will increase production and utilization.

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