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Optimization and Prediction of Operational Parameters for Enhanced Efficiency of a Chickpea Peeling Machine

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Abstract: Chickpeas hold significant nutritional and cultural importance, being a rich source of protein, fiber, and essential vitamins and minerals. They are a staple ingredient in various cuisines worldwide. Peeling chickpeas is considered a crucial pre-consumption operation due to the undesirability of peels for some uses. This study aimed to design, test, and evaluate a small chickpea seed peeling machine. The peeling prototype was designed in accordance with the chickpeas' measured properties; the seeds' moisture content was determined to be 6.96% (d.b.). The prototype was examined under four different levels of drum revolving speeds (100, 200, 300, and 400 rpm), and three different numbers of brush peeling rows. The prototype was tested with rotors of four, eight, and twelve rows of brushes. The evaluation of the chickpea peeling machine encompassed several parameters, including the machine's throughput (kg/h), energy consumption (kW), broken seeds percentage (%), unpeeled seeds percentage (%), and peeling efficiency (%). The obtained results revealed that the peeling machine throughput (kg/h) exhibited an upward trend with increases in the rotation speed of the peeling drum. Meanwhile, the throughput decreased as the number of peeling brushes installed on the roller increased. The highest recorded productivity of 71.29 kg/h was achieved under the operational condition of 400 rpm and four peeling brush rows. At the same time, the peeling efficiency increased with the increase in both of peeling drum rotational speed and number of peeling brush rows. The highest peeling efficiency (97.2%) was recorded at the rotational speed of 400 rpm and twelve peeling brush rows. On the other hand, the lowest peeling efficiency (92.85%) was recorded at the lowest drum rotational speed (100 rpm) and number of peeling brush rows (4 rows). In the optimal operational condition, the machines achieved a throughput of 71.29 kg/h, resulting in a peeling cost of 0.001 USD per kilogram. This small-scale chickpea peeling machine is a suitable selection for small and medium producers.

Keywords: chickpeas seeds; peeling efficiency; prediction model

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1. Introduction

Chickpeas (*Cicer arietinum* L.) rank as the third most important cultivated legume crop in the world after soybeans and dry beans [1,2]. Chickpeas exhibit an approximate composition of 22% protein, 63% carbohydrates, 8% crude fiber, 4.5% fat, and 2.7% ash on average [3]. Because of this rich content of nutrients, chickpeas are an essential ingredient in many traditional dishes of native populations around the world [4]. The regular consumption of chickpeas contributes to the promotion of human well-being through the regulation of fatty acids [5]. Chickpeas represent an economical and significant protein source, particularly for individuals with limited access to animal-based protein or those who follow a predominantly vegetarian dietary pattern. Moreover, chickpeas exhibit favorable attributes in their mineral content (including calcium, phosphorus, magnesium, zinc, and iron), unsaturated fatty acids, dietary fiber, and β-carotene [6,7]. The leaves, stems, and fruit peelings of chickpeas demonstrate an effective capacity for the adsorption of lead ions from aqueous solutions, allowing for the successful accumulation of these ions onto their surfaces [8]. According to the authors of Reference [9], activated carbon was synthesized from chickpea peels using a series of carbonization and chemical processes.

Post-harvest operations, specifically the seed peeling process, have been recognized as crucial procedures that enhance the quality and value of agricultural material [10,11]. The authors concluded that employing a mechanical approach to the peeling process can reduce the time required by approximately 93% compared to manual peeling.

The authors of ref [12] concluded that peeling is a preliminary operation involving the removal of the outer skin using different techniques such as mechanical, steam, chemical, and manual peeling. Advanced methods include infrared and ohmic heating-assisted peeling. Among these techniques, manual abrasive peeling is known to yield high-quality products with minimal flesh loss. However, its suitability for large-scale production is hindered by its labor-intensive and time-consuming nature. Among the various peeling techniques, mechanical methods are deemed advantageous due to their ability to preserve the freshness and integrity of the edible portions of the produce [13].

Emadi et al. [14] The pliability of brushes facilitates the peeling process. It makes use of the maneuverability of the brushes' protrusions across all regions of the treated product. Each protrusion on the brush serves as a diminutive cutting apparatus, proficiently excising and abrasively eliminating the peel pieces. In an investigation conducted by the authors of [15], the impact of peeler speed (ranging from 350 to 750 rpm) and peeling time (varying from five to twelve minutes) on machine performance was examined. The evaluation was based on parameters such as peeling efficiency, percentage weight of peels, and flesh loss. Their findings revealed a positive correlation between peeler rotational speed and peeling efficiency across all tuber samples. In a study conducted by the authors of Reference [16], the experimental results revealed a significant enhancement in the performance of a reciprocating peanut sheller after implementing some modifications (incorporating a feeding mechanism into the sheller, expanding the friction area of the shelling box, and implementing rubber for enhanced shelling). Notably, following the modifications, the reciprocating peanut sheller exhibited improved shelling efficiency and throughput, achieving values of 98.85% and 155.98 kg/h, respectively. These results were obtained under specific operating conditions, including a feeding rate of 160 kg/h, box speed of 1.4 m/s, moisture content of approximately 17.12% (w.b.), and air velocity of 8.37 m/s. In contrast, before the modifications, the shelling efficiency and productivity were measured at 95.32% and 89.20 kg/h, respectively, under a feeding rate of 100 kg/h and other comparable analyzed operating conditions. In the study conducted in ref [17], the authors manufactured and tested a peanut sheller under different drum rotary speeds of 150, 200, 250, and 300 rpm, feeding rates of 170, 210, and 250 kg/h, and air speeds of 4.9, 6.8, and 8.8 m/s. They summarized that shelling efficiency increased with a decrease in both drum rotational speed and feeding rate, and the sheller's throughput increased with the increase in both drum rotational speed and feeding rate.

In the food industry, critical considerations encompass peeling losses, undesired deformation, energy consumption, material wastage, total process cost, and the level of food safety and quality. The prevalent challenges encountered in widely adopted designs encompass challenges in equipment calibration, heightened product loss, and reduced machine efficiency. Additionally, a majority of peeling machine designs are tailored to specific crops, limiting their versatility [13,18,19]. Mousa and Darwish [20] evaluated a newly developed shelling machine designed for peanut pod shelling. The study revealed that the machine exhibited a remarkable level of efficiency in the shelling process. Through a series of experiments conducted within a speed range of 100 to 400 rpm and a clearance range of 9 to 12 mm, the optimal operating conditions for shelling peanut pods were determined to be 200 rpm for speed and 10 mm for clearance. The primary drawback of mechanical peeling resides in the propensity for material loss and deformations. Mitigating material losses and enhancing process quality directly impact the overall efficiency of the food processing industry [21]. To address this, further research is warranted to delve into the technological aspects of these operations.

An economic analysis provides empirical evidence affirming the practical feasibility and economic advantages of the novel design in comparison to traditional peeling methods. In their study, the authors of ref [22] outlined the components of machinery costs, which encompass ownership costs and operating costs.

The main objective of this study was to, develop, test, and evaluate the influence of various operational parameters on the performance of a chickpea peeling prototype and to identify the optimal operational conditions for this prototype according to the following evaluation parameters: highest peeling efficiency, maximum machine throughput, minimum consumed specific energy, lowest percentages of broken and unpeeled seeds, and enhancement of the quality of the peeled chickpea seeds.

2. Materials and Methods

2.1. The Description of the Adopted Chickpea

The chickpea seeds utilized in the investment were obtained from a local market. Then, their moisture content was determined according to the method described by the authors of ref [23], yielding a measurement of 6.96% on a dry basis (d.b.). The development, examination, and evaluation of the chickpea seed peeling prototype took place in the workshop of the College of Agricultural Engineering, Al-Azhar University, Cairo, Egypt. We took into consideration the physical, mechanical, and aerodynamic properties of seeds listed in Table 1. Throughout the manufacturing process, particular attention was given to ensuring the prototype's operational safety, compact size, and lightweight characteristics, aiming to enhance its mobility and maneuverability.

Table 1. Some physical, mechanical, and aerodynamic properties of chickpea seeds.

Property (Unit)	Value	S.D.
Length (mm)	7.65	0.40
Width (mm)	6.45	0.27
Thickness (mm)	5.71	0.20
Sphericity (%)	85.72	2.41
Geometrical diameter (mm)	6.55	0.24
The angle of repose (degree)	26.57	0.91
Friction coefficient	0.41	0.02
Compression force (N)	45.7	3.95
Critical airspeed (m/s)	7.65	0.52
1000 Seed mass (g)	173.85	2.43

2.2. Peeling Prototype Description

The main components of the chickpea seeds peeling machine included: a frame, feed hopper, peeling chamber, outlet for seeds, outlet for shells, and a power source, as shown in Figure 1. The design and endurance testing of the chickpea peeling machine was conducted utilizing SolidWorks 2023 software, with careful consideration given to the distinct physical and mechanical properties of chickpea seeds.

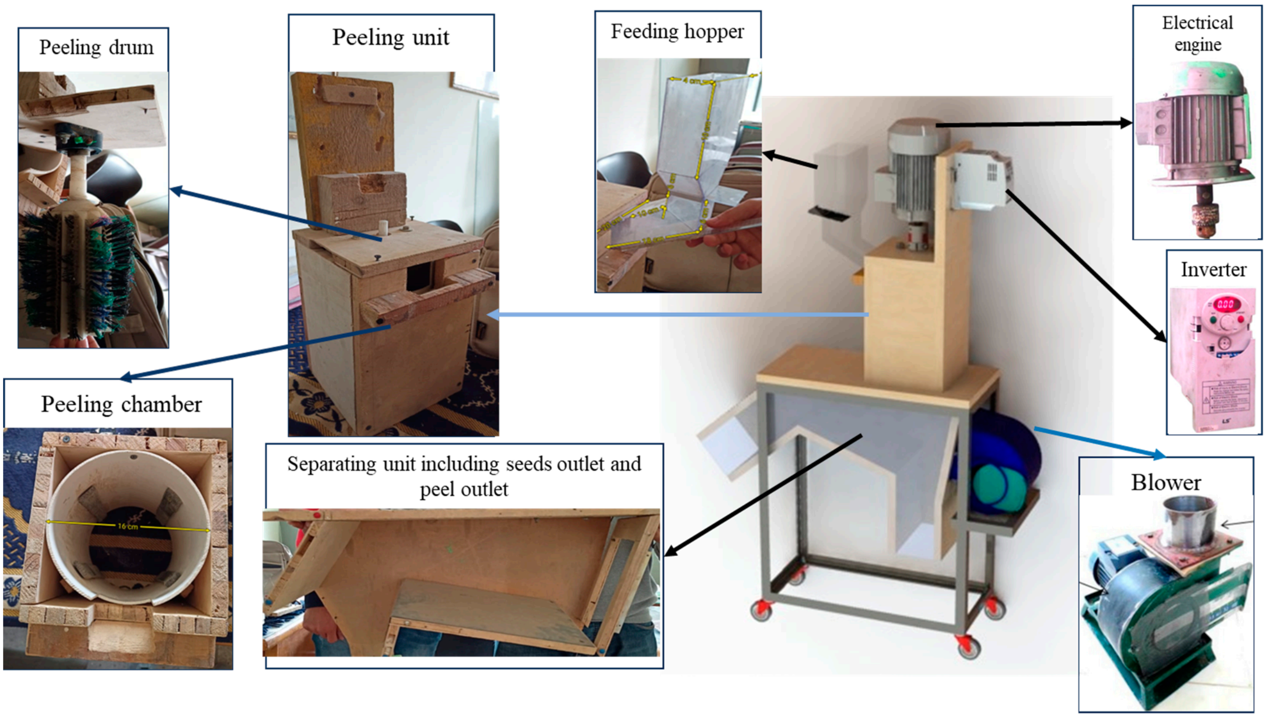

Figure 1. A 3D module for chickpea seeds peeling prototype and photos of its parts.

2.2.1. Feeding Hopper

The feeding hopper was constructed using a 2 mm thick fiberglass sheet, forming a conical shape. The top section of the hopper featured rectangular dimensions of 150 × 180 mm, while the bottom section measured 80 × 60 mm, with a height of 160 mm.

2.2.2. Peeling Chamber

The peeling chamber, which was fabricated from wood in our design prototype, plays a crucial role in effectively removing the outer shells from chickpea seeds. Inside is a vertical cylinder made of PVC, with dimensions of 155 mm for the inner diameter and a height of 300 mm.

To enhance the peeling process, four rubber fins are affixed to the inner surface of the peeling chamber, parallel to the longitudinal axis. These fins measure 176 mm in length, 30 mm in width, and 10 mm in thickness. The presence of rubber fins within the peeling chamber reduces the occurrence of seed vertexing, which increases the peeling efficiency.

Inside the cylinder, a vertical rotating drum made from Artalon (the peeling drum) is directly attached to the power source of the peeling chamber. The drum features twelve grooves (rows) along the longitudinal axis, allowing easy control of the number of peeling brush rows in use. Positioned below the outlet opening for the chickpea seeds is a blower, which is adjustable to control the airflow speed. Its purpose is to clean the seeds by removing any remaining shell fragments and dust. An air speed of 4 m/s was used in accordance with the measured critical airspeed of chickpea seeds (7.65 m/s). The elevation and plan of the peeling chamber can be observed in Figure 2. The peeling brushes are composed of twelve metal bases, with plastic bristles affixed to each base. The plastic bristles are 35 mm long.

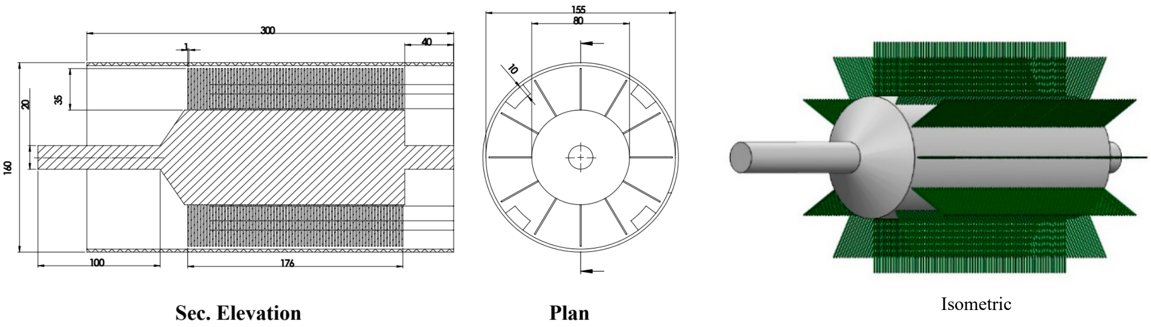

Figure 2. Elevation, plan, and isometric of the peeling chamber. Dims, mm.

2.2.3. Power Source

An electric motor (0.25 kW) was used as a power source for this peeling prototype. The motor is connected to an inverter device to increase or reduce the rotary speed of the electric motor.

2.3. Theoretical Basis

In the scenario in which the chickpea seed descends freely from the top to the bottom of the vertical peeling chamber, the duration of its residence inside the chamber is influenced by the length of the peeling chamber. Consequently, the following equation can determine the seed's residence time:

$$t = \sqrt{\frac{2l}{g}} \quad (1)$$

where t is the theoretical residence time inside the peeling chamber (second), l is the peeling chamber length (m), and g is the gravity (m/s^2).

From Equation (1), the residence time of chickpea seeds inside the peeling chamber can be calculated. In our prototype, the residence time was approximately 0.2 s. During this short period, the seed will be hit by the peeling brushes multiple times, and the frequency of these hits depends on both the rotational speed of the peeling drum and the number of brushing rows attached to the peeling drum as presented in Figure 3.

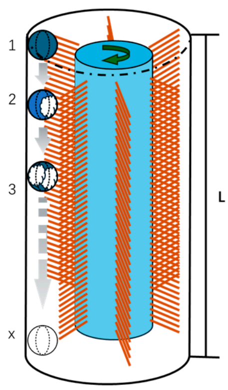

Figure 3. Influence of peeling chamber length on chickpea seed residence time and brushing frequency.

When the chickpeas were poured into the peeling machine, their shucks would be scratched off by a roller stuck with brushes. The peeling efficiency determined the peeling machine's energy consumption, which was dictated by the drum rotation speed necessary to match the peeling ability of each brush. The chickpeas were decorticated in a peeling machine, invisibly and randomly. Therefore, a statistical model was necessary to provide evidence of peeling efficiency.

The peeling process of chickpeas is random and difficult to observe. By counting the number of peeling times and the overall peeling rate of the chickpeas in the peeling process, the model predicted the single scratching peeling ability of the brush. The experimental results show that the model can be used to evaluate the peeling ability of the chickpea peeler, reduce the energy consumption of the peeler, and improve the peeler's working energy efficiency.

We divided a chickpea's shuck into 10 pieces and assumed that x ($1 \leq x \leq 9$) pieces would be scratched off by each brushing. The probability that all of the shuck would be scratched off was:

$$P\left(\sum_{i=1}^{10} x_i\right) = 1 - C_{10}^{1} \times P(A_1)^n + C_{10}^{2} \times P(A_2)^n - \cdots\cdots + C_{10}^{8} \times P(A_8)^n - C_{10}^{9} \times P(A_9)^n \quad (2)$$

where $P(A_k)^n$ was the possibility that k pieces would not be scratched off after n brushings.

Then

$$P(A_k) = C_{10-k}^{x} / C_{10}^{x} \quad (3)$$

The results of the prediction model are presented in Figure 4.

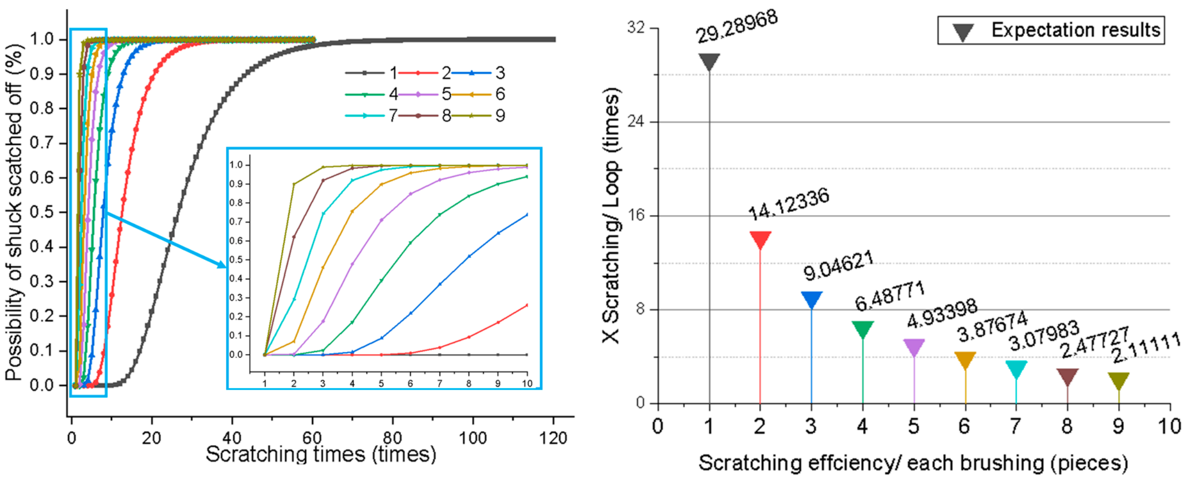

Figure 4. The prediction results of the statistical and expectation models.

2.4. Experimental Design

The peeling prototype was tested at four different rotational speeds of the drum (100, 200, 300, and 400 rpm) (0.78, 1.57, 2.35, and 3.14 m/s). The rotational speed was determined using a non-contact, digital photo tachometer with a laser photo mechanism; the measurement range of the device spans from 2.5 to 99,999 rpm. Its precision is rated at 0.1 rpm within the speed range of 2.5 to 999.9 rpm and increases to 1 rpm for values exceeding 1000 rpm. There are three different peeling rotors. Each rotor has a different number of peeling (brush) rows, specifically 4, 8, and 12 rows. The study parameters' influence on the peeling machine's performance was assessed using SPSS 20 software. The analysis involved employing a two-way analysis of variance (ANOVA) method, followed by the least significant difference (LSD) test ($p < 0.05$). The experimental setup and data analysis were carried out using a randomized complete block design [24].

2.5. Measurement

2.5.1. Machine Throughput

The machine's throughput was determined by evaluating the ratio between the quantity of peeled chickpea seeds and the duration of the peeling process, as expressed by the following mathematical equation:

$$P_m = \frac{M_t}{t} \quad (4)$$

where P_m represents the prototype throughput in (kg/h), M_t denotes the total mass of seeds in kilograms (kg), which was measured using a digital electric balance with an accuracy of 0.01 g (g), and t signifies the duration of the peeling process, measured in hours (h). A stopwatch was employed to accurately measure the duration of the process.

2.5.2. Power Requirements

The power requirement (W) for the peeling process was determined using the following equation [25]:

$$Power\ consumption = I \times V \times cos\ \times \eta_m \tag{5}$$

where I is the consumed current with load (Amperes), V is the voltage difference (Volts), *cos ø* is the power factor assumed as a 0.80 phase angle between current and voltage, and η_m is the mechanical efficiency of the motor, assumed as 85%.

2.5.3. The Specific Energy

The specific energy (kWh/ton) was considered by dividing the consumed power (kW) by the machine's throughput (t/h).

2.5.4. Broken Seeds Percentage

The broken seeds percentage was calculated as follows:

$$B_S(\%) = \frac{M_{BS}}{M_t} \tag{6}$$

where B_s refers to the broken seed percentage (%) and M_{BS} is the mass of broken seeds (kg).

2.5.5. Unpeeled Seeds Percentage

The unpeeled seeds percentage was computed according to the following formula [26]:

$$P_u = \frac{M_u}{M_t} \times 100 \tag{7}$$

where P_u is the percentage of seeds left unpeeled (%) and M_u is the mass of the unpeeled seeds (kg).

2.5.6. Peeling Efficiency

Peeling efficiency was computed according to the following formula [26]:

$$\eta_p(\%) = \frac{M_t - M_u}{M_t} \times 100 \tag{8}$$

2.6. Operating Cost Calculation ($/h)

The comprehensive calculation of the total operating cost incorporated both fixed costs and variable costs. The determined total cost was outlined as the following equation [27]:

Total cost ($/h) = Fixed cost ($/h) + Variable cost ($/h)

A. *Fixed costs:*

1. Depreciation cost:

Depreciation of the machine was calculated according to the following equation:

$$D = \frac{(P - S)}{L} \tag{9}$$

where D is the machine depreciation ($/year), P is the purchase price (manufacturing price) $, S is the salvage or selling price $ (0%), and L is the time between the buying and selling year.

2. Interest rate cost:

The interest rate was incorporated as a percentage of the machine's purchase price in Egypt. It was set to 5% per year.

3. Taxes, insurance, and shelter:

The cost of taxes, insurance, and shelter was incorporated as 2% of the machine's purchase price per year [22].

$$Fixed\ costs\ \$/\mathrm{h} = \frac{Depreciation\ cost + Interest\ rate\ cost + Taxes,\ insurance,\ and\ shelter}{hours\ of\ use\ per\ year} \tag{10}$$

B. Variable costs:

1. Repair and maintenance costs were calculated using the following formula [28]:

$$Repair\ and\ maintenance\ costs\ \$/\mathrm{h} = \frac{100\%\ Depreciation\ costs}{hours\ of\ use\ per\ year} \tag{11}$$

2. The consumed power cost was calculated according to the following equation:

$$power\ cost\frac{\$}{\mathrm{h}} = consumed\ power\ (\mathrm{kW.h}) \times price\ of\ power\ unit\ (\mathrm{kW})\$ \tag{12}$$

3. Labor costs were calculated as:

$$Labor\ costs = Salary\ of\ one\ worker \times Number\ of\ workers$$

Variable costs were determined as:

$$Variable\ costs = repair\ and\ maintenance\ costs + power\ cost + Labor\ costs$$

3. Results and Discussions

3.1. Statistical Analyses

Table 2 presents the results of the analysis of variance conducted to assess the statistical significance of the study parameters (drum rotational speed, brush peeling rows, and their interaction) impacting the performance metrics of the chickpea seed peeling machine. The performance metrics evaluated include throughput, power requirements, broken seeds, unpeeled seeds, and peeling efficiency. The statistical analysis indicated significant impacts of the study variables and their interaction on the machine's throughput and the required power, both at a probability level of 1%. Among the study parameters, the drum rotational speed exhibited a more substantial influence compared to the number of rows and the interaction between the variables. The specific energy demonstrated a significant sensitivity to the number of brush rows and the interaction between the study parameters, with a probability level of 1%, while the drum rotational speed had a significant impact at a probability level of 5%. The broken seed and unpeeled seed percentages were significantly influenced by the study parameters at a probability level of 1%, although their interaction was not found to be significant. Peeling efficiency, on the other hand, exhibited significant effects at both probability levels of 1% and 5% due to the number of rows and drum rotational speed, while the interaction between these factors was not statistically significant.

Table 2. Analysis of variance table for main treatments and interactions.

Source of Variation	df	F Value					
		Throughput	Power	Specific Energy	Broken Seed	Unpeeled Seed	Peeling Efficiency
Drum speed	3	549.647 **	1054.786 **	3.69 *	104.475 **	24.068 **	4.031 *
Rows number	2	412.129 **	536.363 **	558.95 **	94.309 **	46.227 **	8.550 **
Drum speed × rows number	6	9.805 **	9.835 **	4.93 **	0.468 ^{ns}	1.574 ^{ns}	0.368 ^{ns}
Error	24						

** Significant at 1%. * Significant at 5%. ^{ns} non-significant.

3.2. Machine's Throughput

Figure 5 illustrates the relationship between the machine's throughput in (kg/h) and the rotational speed of the drum for different configurations of brush peeling rows on the drum. The obtained data showed that the increase in drum rotational speed from 100 to 400 rpm corresponded with an increase in machine throughput, in line with [24,29]. Meanwhile, an increase in the number of brush peeling rows on the drum was found to be associated with a decrease in machine throughput. The highest recorded machine throughput value was 71.29 kg/h, achieved at a drum rotational speed of 400 rpm and using 4 peeling brush rows. In contrast, the lowest recorded machine throughput value was 29.39 kg/h, observed at a drum rotational speed of 100 rpm using 12 peeling brush rows. The observed increase in the machine's throughput at higher drum rotational speeds can be attributed to the accelerated movement of seeds, resulting in a quicker expulsion from the prototype. Conversely, the increase in brush peeling rows impedes the rapid descent of seeds from the exit hole, thereby affecting the machine's throughput.

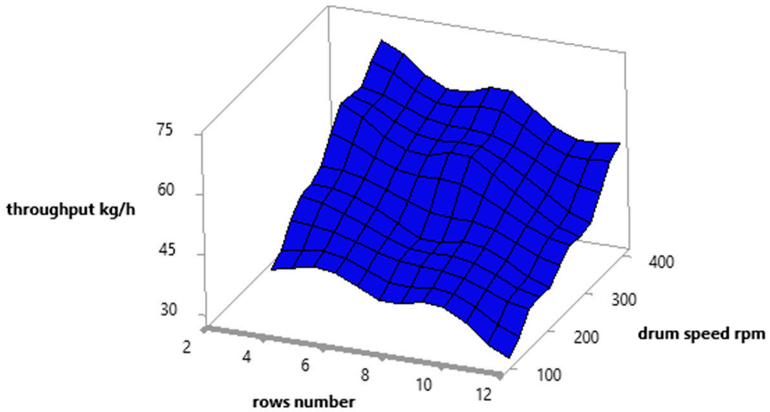

Figure 5. Machine's throughput "kg/h" at different brush row numbers and different drum rotational speed "rpm".

3.3. Power Requirements and Consumed Specific Energy

Figure 6 illustrates the correlation between power requirements (shown as vertical bars), consumed specific energy (shown as lines), and drum rotational speed for various configurations of brush peeling rows. The results indicate a substantial increase in power requirements at higher drum speeds and when using an increasing number of brush peeling rows. This result agrees with [30]. The lowest recorded power requirement was 79.29 W, observed under the operational conditions of a drum rotational speed of 100 rpm and four brush peeling rows. On the other hand, the highest power requirement of 187 W was recorded at a drum speed of 400 rpm and twelve brush peeling rows. The observed increase in power requirements with increasing drum rotational speed can be attributed to the logical relationship between rotational speed and power consumption. The increase in power requirements with an increasing number of brush peeling rows may be attributed to factors such as the additional weight of the drum and the increased friction between the moving parts and the seeds. On the other hand, the data presented in the figure illustrate that the number of brush peeling rows had a more pronounced impact on the consumed specific energy than the drum rotational speed. Generally, there was a discernible increase in the consumed specific energy with an increase in the number of peeling rows. The substantial rise in the consumed specific energy observed with an increase in the number of peeling brush rows can be attributed to the amplified power requirement and reduced throughput associated with a higher number of brushes. Meanwhile, the slight effect the drum's rotational speed had on the consumed specific energy appears to be a positive effect of increasing the rotational speed on the machine's productivity; the effect mostly disappeared with the increase in energy requirements that occurred at the same time.

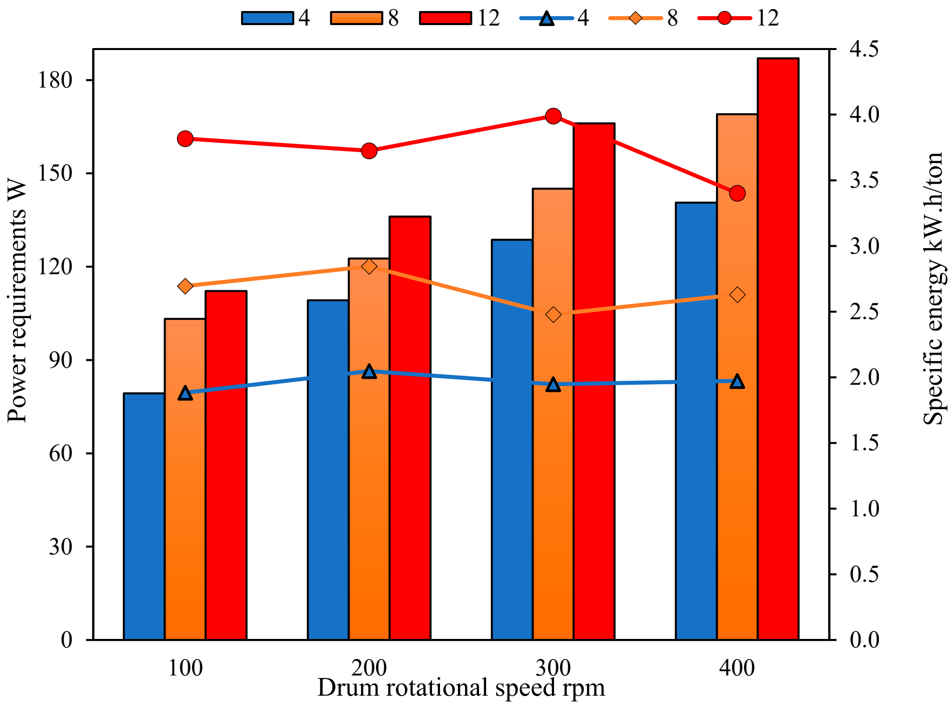

Figure 6. Effect of drum rotational speed on the power requirements (columns) and consumed specific energy (lines) at different numbers of peeling brush rows.

3.4. Broken Seed Percentage

Figure 7 depicts the relationship between the percentage of broken seeds and drum rotational speed at different numbers of brush peeling rows. The findings indicate a direct correlation between the percentage of broken seeds and both drum speed and the number of brush peeling rows. This result agrees with [13,24]. The lowest recorded value for the percentage of broken seeds was 1.60%, observed under the operational conditions of a drum rotational speed of 100 rpm and four brush peeling rows. The highest recorded value for the percentage of broken seeds (5.75%) was obtained at a drum rotational speed of 400 rpm and twelve brush peeling rows. The broken seed percentage increased as the drum rotational speed and the number of brush peeling rows increased. This can be attributed to the increase in the force and frequency of impacts on the seeds caused by the higher drum rotational speed and the larger number of brush peeling rows.

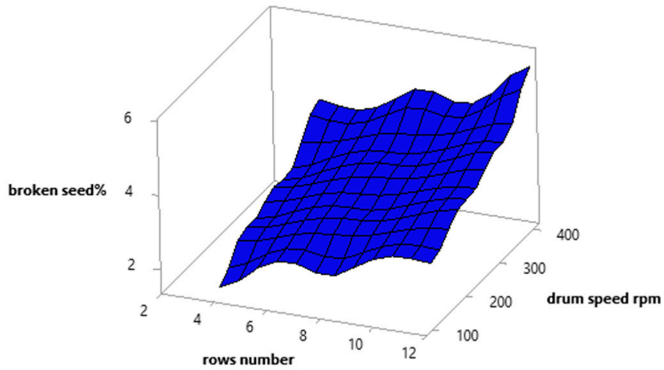

Figure 7. Broken seed percentage "%" at different brush row numbers and different drum rotational speeds "rpm".

3.5. Unpeeled Seed Percentage

Figure 8 illustrates the correlation between the percentage of unpeeled seeds and the drum rotational speed for varying numbers of rows on the drum. In general, an increase in both drum rotational speed and the number of brush peeling rows was found to be associated with a decrease in the percentage of unpeeled seeds. This result agrees with [20]. The lowest recorded value for the percentage of unpeeled seeds was 2.90%, observed at a drum rotational speed of 400 rpm and twelve brush peeling rows. Conversely, the highest recorded value for the percentage of unpeeled seeds (7.15%) was obtained at a drum rotational speed of 100 rpm and four brush peeling rows. When the drum rotational speed is higher, there is a greater centrifugal force acting on the seeds, causing them to experience stronger impacts against the brush surfaces. This increased impact force helps to dislodge the outer peel from the seeds more effectively, resulting in a lower percentage of unpeeled seeds. Similarly, increasing the number of brush peeling rows provides more opportunities for the seeds to come into contact with the brushes. This increases the overall brushing action and improves the chances of removing the outer peel from the seeds. Consequently, a higher number of brush peeling rows contributes to a reduced percentage of unpeeled seeds. Overall, the combination of higher drum rotational speed and an increased number of brush peeling rows enhances the peeling process, leading to a lower percentage of unpeeled seeds.

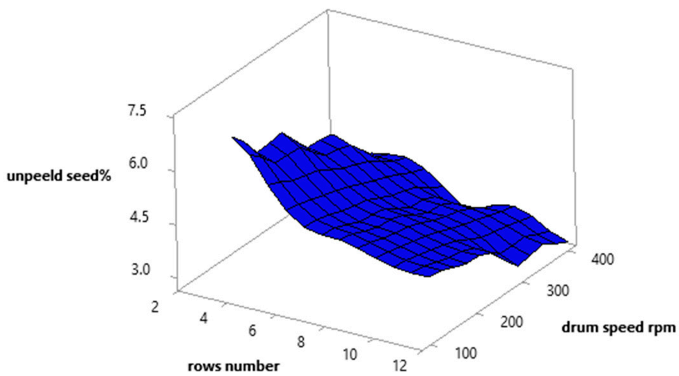

Figure 8. Unpeeled seed percentage "%" at different brush row numbers and different drum rotational speeds "rpm".

3.6. Peeling Efficiency

The findings depicted in Figure 9 indicate a positive correlation between both drum rotational speed and the number of brush peeling rows and peeling efficiency. Increasing drum rotational speeds generally resulted in higher average peeling efficiencies. This result agrees with refs [31,32]. The highest recorded value for peeling efficiency was

97.10%, observed under the operational conditions of a drum speed of 400 rpm and twelve brush peeling rows. Conversely, the lowest recorded value for peeling efficiency was 92.85%, observed at a drum rotational speed of 100 rpm and four brush peeling rows. Increasing the drum rotational speed leads to a higher velocity of seed movement within the machine. This increased speed enhances the kinetic energy of the seeds and the interactions between the seeds and the brushes. As a result, a higher drum rotational speed typically corresponds to an improved peeling efficiency. The increased kinetic energy and more vigorous brushing action aid in the removal of the outer peel from the seeds, leading to a higher peeling efficiency. Similarly, increasing the number of brush peeling rows provides more opportunities for the seeds to come into contact with the brushes. This increases the overall brushing action and improves the chances of removing the outer peel from the seeds. Consequently, a higher number of brush peeling rows contributes to a higher peeling efficiency.

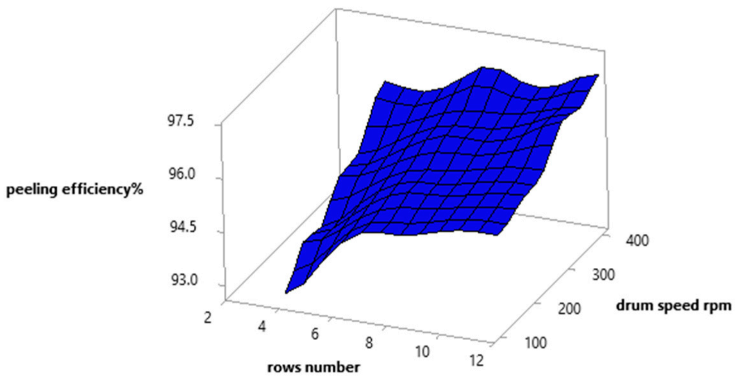

Figure 9. Peeling efficiency "%" at different brush row numbers and different drum rotational speeds "rpm".

Figure 10 shows the chickpea seeds before and after the peeling process and the extracted peels.

Figure 10. Chickpea seeds before peeling (**left**), after peeling (**middle**), and the peels (**right**).

3.7. Prediction Results

Figure 11 illustrates the relationship between scratching times (number) and the probability that the shuck will be scratched off. It can be noted that the results of the prediction module match the experimental results. The figure illustrates that when the arithmetic (experimental) frequency of chickpea seed impacts by the peeling brushes (dependent on the peeling drum rotational speed and the number of rows of peeling brushes) is equivalent or proximate, they reside within the same region as the probability of peel detachment. For instance, at a seed impact frequency of 2.7, under two operational scenarios, namely 200 rpm with four rows of peeling brushes and 100 rpm with eight rows of peeling brushes, the novel model predicts that the likelihood of chickpea peeling is comparable.

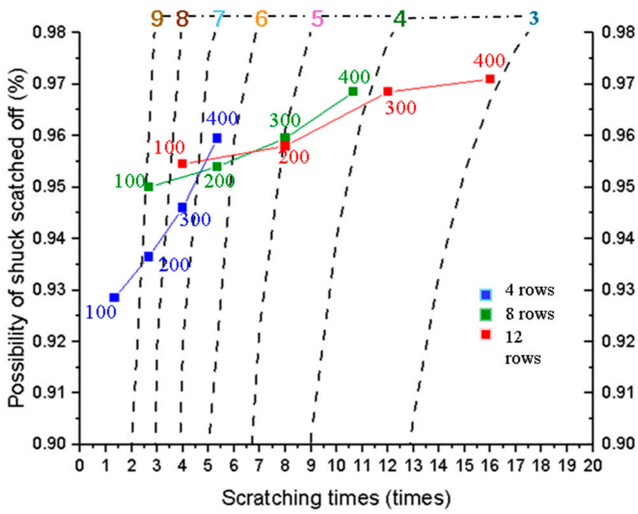

Figure 11. Relationship between scratching times and the probability of shuck removal in chickpea peeling.

3.8. Cost Analysis

Table 3 presents the consumption and operating costs associated with the chickpea peeling unit. The table encompasses the total fixed costs (0.05 $/h), which encompass depreciation costs, interest costs, taxes, insurance, and shelter costs. It also includes variable costs ($0.61) arising from machine operation, such as repair and maintenance costs, labor costs, and power costs (at the optimal operational condition). According to the table, the total cost is $0.66. With a 71.29 kg/h throughput in the optimal operational conditions, the peeling cost for 1 kg is 0.01 U.S.D. (United States Dollar) which is equal to 0.4 E.L. (the Egyptian currency).

Table 3. Fixed and variable costs of peeling module.

Item	Cost $ (E.L is the Egyptian Currency)
Peeler price $ (U.S.D)	$100 (4100 E.L)
Depreciation costs $/year	12.5 $/year (525 E.L/year)
Interest costs $/year	5 $/year (210 E.L/year)
Taxes, insurance, and shelter costs $/year	2 $/year (84 E.L/year)
Fixed costs in $/h	0.05 $/h (2.1 E.L/h)
Repair and maintenance costs $/h	0.005 $/h (0.22 E.L/h)
Labor costs $	0.6 $/h (25 E.L/h)
Power cost $/h	0.0045 $/h (0.2 E.L/h)
Variable costs	0.61 $/h (25.6 E.L/h)
Total cost	0.66 $/h (27 E.L/h)

4. Conclusions

The peeling process is of paramount importance in evaluating the quality of the final product, and the utilization of peeling machines brings forth notable advantages in terms of improved product quality, shortened processing time, and reduced labor demands. Based on the experimental findings of the tested model, the authors recommend considering operational conditions of 400 rpm for the drum rotational speed and four rows of peeling brushes to be the optimal operation condition. This operating condition recorded the highest productivity (71.29 kg/h) and achieved a peeling efficiency (95.95%) close to the maximum recorded peeling efficiency (97.10).

The authors intend to conduct a simulation using specialized software programs to predict the efficiency of the peeling process. Additionally, they plan to investigate the impact of the blower's airspeed on the separation of peels from seeds. Furthermore, the authors aim to incorporate FNN (Feedforward Neural Network) machine learning techniques to determine the optimal operational conditions as an electronic method in this field.

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