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Design, Fabrication and Performance Evaluation of a Rotary Drum Abrasion, Continuous Type Peeling Machine for *Solanum Tuberosum* (Potato)

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ABSTRACT

Peeling and washing of potato tubers are the basic unit operations required to perform at the beginning of potato processing into any form of processed product. Most of the currently available peelers are batch type and it was reluctant to fulfil the user's needs. Therefore, a rotary abrasion peeling cum washing, continuous type peeler was designed and fabricated to meet Sri Lankan medium and large-scale food processors requirements. The machine was composed of integration of abrasion drum and fibre brushes. The undulated surfaces of potatoes were peeled by fibre brushes while the abrasion drum lead to peel the rest of them and the drum was being rotated. A water spraying unit was fixed inside the drum to facilitate efficient peeling and cleaning when potatoes were being peeled. The capacity of the machine was 100 kgh^{-1} with the peeling efficiency of 87.57%, percentage mass loss of 3.58% and damage percentage of 4.24%, respectively. The optimum horizontal drum angle and rotating speed were 10° and 75 rpm. The performance of the newly fabricated machine was compared with the commonly practiced manual peeling with knife. The result revealed that peeling capacity 15 times higher than the manual method in comparison to the manual method while 14-fold decrease in the cost of operation and 15-fold decrease in labour requirement for the new peeler. Moreover, the break-even point value was recorded to be 608 $kgyr^{-1}$. Therefore, it can be concluded that the newly fabricated potato peeler is appropriate for medium and large-scale food processors in Sri Lanka.

1. Introduction

The outer skin of vegetables is known as the peel or rind, which protects the internal parts of the vegetables. Most of the times outer skins are removed due to preference, habit or to reduce exposure to pesticides, reduced product losses, types of products intended to produce, minimizing heat ring formation, minimizing the environmental pollution and to lower the energy and chemical usage [1]. The process of removal of outer skin of vegetables is known as peeling which refers to separating the outer skin [2]. This is a very basic unit operation performed before food processing at the household level, hotels, restaurants, and in the food industry. Naturally, most of the fruits and vegetables such as Ambarella (*Spondias dulcis*), mango (*Mangifera indica*), guava (*Psidium guajava*), Veralu (*Elaeocarpus serratus*), citrus (*Citrus limon*), and vegetables such as potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), beat root (*Beta vulgaris*), etc. are spheroidal in shape and some of them are used for commercial processing as well.

Solanum tuberosum (Potato) is second mostly produced tuber crop next to cassava in Sri Lanka, which is consumed as a vegetable and used for commercial processing of various food products [3]. It is also one of the most important food crops in the world next to wheat, rice, and maize [4]. Potato is a good source of energy, and it consists of considerable amount of daily requirement values (DRV) of essential nutrients. Processing is done for raw potatoes to convert them into edible form. Furthermore, the demand of potato as vegetable is shifting to value-added potato products due to many reasons such as, rising urban population, increasing women engagement with workforce, rising incomes, diet diversification, and busy lifestyles. Therefore, a plenty of potatoes is processed to meet rising demand for convenient foods and snacks [5].

To prepare processed foods from row potato tubers, peeling off and washing are vital unit operations. Therefore, peeling method for potato is a point of interest. Simply peeling methods of fruits and vegetables can be classified into three categories i.e., Thermal peeling, Chemical peeling, Mechanical peeling. Thermal peeling is frequently used for tough and thick skin fruits and vegetables (Pumpkin and Melon), which can be performed in two methods: wet heat (steam, refrigerant) or dry heat. The principle of thermal peeling is by cracking the outer skin into small pieces by the aid of temperature, pressure and electronic devices. The principle behind chemical peeling is by dipping fruits and vegetables in a caustic solution of NaOH (Lye) to loosen and remove the outer skin. However, it has several disadvantages such as, high cost for NaOH solution, loss of quality due to chemical reactions and difficult to remove trace chemicals which can be poisonous [6].

Manual peeling is quite possible for any kind of fruits or vegetable. However, it has major limitations such as, high peeling loss, high time & labour requirement, and contamination with atmospheric air in comparison to the mechanical peeling. Therefore, mechanical peeling has become the most popular among the food processors [7].

Several potato mechanical peelers have been developed based on various principles such as, abrasive peeling and blade peeling techniques. Such types of machines are being used commonly in Sri Lanka as well. Most of these machines are batch type, high in initial cost, high in peeling losses with low peeling efficiencies and majority of those could be used only for one purpose such as potato peeling. As such, these machines are not popular in Sri Lankan food industry. Keeping the above facts in view, this study aims to develop a simple continuous type of abrasion peeling machine for *Solanum tuberosum* (Potato) in order to address all the drawbacks mentioned above.

Since, most of the Sri Lankan food processors are sustaining from marginal profits, affordability of the machine was highly considered. Moreover, the possibility of domestic level maintenance and repairs were also considered. Furthermore, acceptable efficiency of working, safety of the operator, reduction of drudgery, low labour requirement and durability were also considered in the design.

2. Material and Methods

Designing, fabrication testing and evaluation of the machine were carried out in the engineering workshop of the Faculty of Agriculture, Rajarata University of Sri Lanka, Puliyankulama, Anuradhapura.

2.1 Preliminary Experiments

Preliminary experiments were carried out to determine the optimum dimensions for the machine to reduce the material wastage, time, and cost. Some physical properties of four-month-old potato (*Granola* variety) were important to decide the size and shape of the machine components. Therefore, the samples of selected potato variety were divided into five mass categories i.e.,a-0-50 g, b-50-100 g, c-100-150 g, d-150-200g and e- >200g and length, width, and thickness of them were measured using a Venire calliper with 0.01 accuracy. Bulk density was determined using the mass-volume relationship by filling an empty plastic container of predetermined volume (4500 cm^3) with samples and weighing it; then the bulk density (ρb) was determined by dividing the weight of the samples by the container volume [8, 9, 10, 11]. The following equations were used to calculate the equivalent diameter (Geometric mean diameter; D_{eq}), Surface area (S), Sphericity (ϕ) and Bulk density (ρb) [8, 12].

$$D_{eq} = \sqrt[3]{L \times W \times T}$$

Where; L - length, W -Width, T - thickness, D_{eq} - equivalent diameter.

$$S = \pi\,(D_{eq})^2$$

Where; S - surface area, Deq - equivalent diameter.

$$\phi = \frac{D_{eq}}{L}$$

Where; ϕ - Sphericity, L – L - length.

$$\rho b \;=\; M_f \,/\, V_C$$

Where; ρ_b - Bulk density, M_f – Mass of food materials, V_C – Volume of the container.

The fixed funnel method was used to determine the angle of repose of potato tubers [13].

2.2 Factors Considered in Designing

While designing the peeler, the following factors were taken into account.,

Affordability

Cost factor

User friendliness

Peeling capacity

Peeling losses

2.3 Designing and Fabrication of the Machine

Peeling of raw food material is required to go through series of steps i.e., feeding raw food material into peeling mechanism, separating inedible outer skin from the edible fleshy, washing peeled food to achieve cleaner and hygienic product, and collecting peeled food material separately from residual.

Therefore, it was decided to mechanize this process as four integrated units i.e., feeder, rotary abrasion drum, water spraying unit & outlet and draining unit (Figure1).

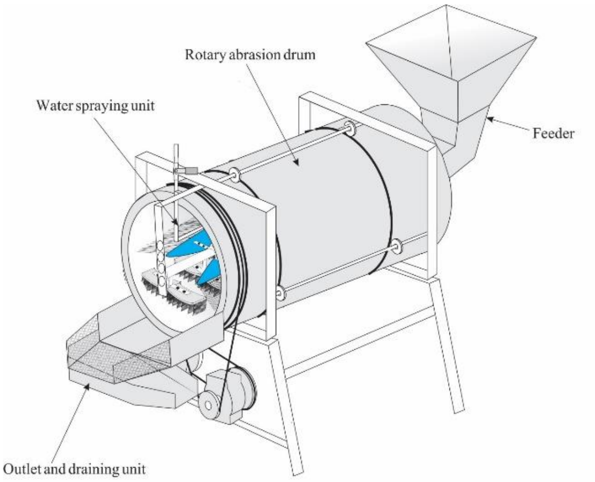


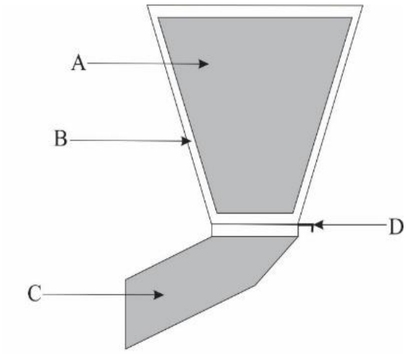
Figure 1: Abrasion peeling machine

- **Designing of Feeder**

Abrasion drum is the place where raw food material is peeled off continuously. Direct feeding of unpeeled raw foods into the rotating drum is a risk for the operator. On the other hand, it is difficult to maintain continuous feeding flow and causes to reduce peeling capacity and efficiency. By considering all the above factors, a gravity-flow feeder was designed to facilitate the feeding task. The feeder consists of feeding hopper, sliding flow control gate and conveyer tube. The hopper involves in storing unpeeled food material temporary and conveyer tube helps to carry food from the hopper to the peeling drum while the gate involves controlling the food flow from hopper to conveyer tube. Figure 2 shows the main components of the feeder.

Preliminary studies were recorded that 640 kg m^{-3} of bulk density for potato (*Granola* variety). Based on that, the volume for the hopper was decided as 62500 cm^3 to accommodate 40 kg of unpeeled potatoes.

It was decided to have the shape of the hopper as a frustum of a square pyramid to improve the flow of food materials into peeling drum, under the gravity.



A- Hopper, B – Frame of hopper,
C- conveyer tube, D –Flow control gate

Figure 2: Side view of feeder

According to the volume of the hopper, the dimensions were calculated using the following equation (01) which shows the relationship among volume, areas of the upper and lower bases and perpendicular height of the frustum of squire pyramid [14].

$$V = \left(\frac{h}{3}\right)[A1 + A2 + \sqrt{A1}A2 \quad —— [01]$$

Where; V – Volume of the frustum, h - Perpendicular height of the frustum, A_1 – Area of the upper base, A_2 – Area of the lower base.

The dimensions of the upper base were decided as 50 cm x 50 cm square based on the overall dimensions of the machine and the dimensions of the lower base were taken as 20 cm x 20 cm, providing enough space to flow food into the conveying tube without bridging at the base of the hopper. Considering the above dimension, the calculated values of perpendicular height (h), slanted length (l) and the angle of slope (α) of the hopper were 50 cm, 52.2 cm and 73°25" respectively.

- **Designing of abrasion drum**

The abrasion drum was designed into a cylindrical shape with double walls. The designed capacity of the drum was 10 kg of unpeeled potato. The inner wall was abrasion which involve in peeling potato by abrasion. The overall abrasion surface was evenly indented as 36 protrusions per 8 cm^2. The size of a protrusion is 4 mm x 1 mm length and width, respectively. The sheet was punched from one side with a die at a fixed spacing to develop the protrusions. The centre to centre spacing between rows and columns of protrusions were 16 mm and 8 mm, respectively (Figure 3).

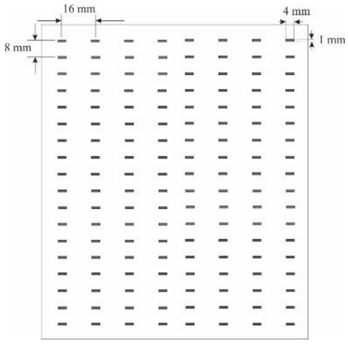


Figure 3: Abrasion Plate

In addition to the abrasion surface, two sets of fibre brushes were placed inside the drum such a way that, radially downward in the interest of peel off undulated surfaces on the food materials while the drum was rotating (Figure 4).

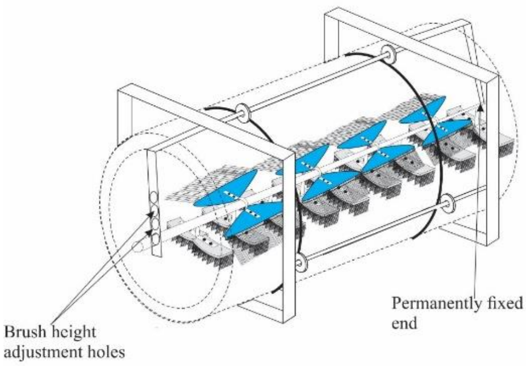


Figure 4: Arrangement of brushes inside the drum

The abrasion inner drum wall was fixed with the outer drum by the means of semi-permanent fastening method of nuts and bolts to facilitate the easy maintenance and repair. A gap of 2 cm was kept between the outer wall and abrasion inner wall to avoid the clogging of abrasion plate from residuals food materials meanwhile peeling was progressed. Beside the drum with the frame was made in such a way that the horizontal inclination could be adjusted towards the outlet employing screw drive mechanism which was designed at the front side and hinges at the backside of the drum (Figure 5).

The drum was mounted on three sets of bearings drive shafts which were permanently fixed with the frame in 120º of the angle between each drive shaft was consisted of two bearings which were contacted with the outer surface of the drum where bearing guiding rails were designed with the purpose of aligning the bearing on the outer wall of the drum (Figure 6).

Single phase 3 hp electrical motor was selected as the power source. A gearbox with 10:1 ratio was used between the motor and the drum to reduce motor speed. Belts and pulleys were selected as the power transmission method because the electrical motor is protected by the overloaded condition. The preliminary studies revealed that the optimum drum speed for potato peeling was to be 75 rpm. Therefore, the pulley diameters were selected as Pulley 1 - 20.23 cm, Pulley 2 – 7.62 and Pulley 3 – 10.16 cm in diameter, respectively. However, the drum slop could be changed, it was difficult to align belt when the drum makes slop towards the outlet. Therefore, the two guiding rails were designed instead of pulley at the backside of the drum in the interest of facilitating a track for the belt (Figure 7).

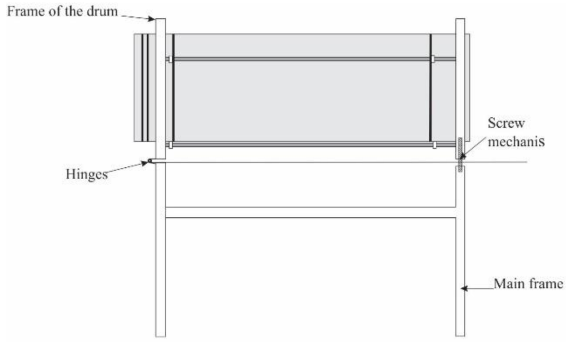


Figure 5: Drum inclination adjustment

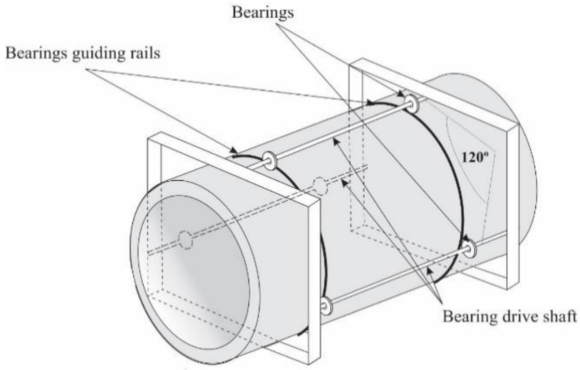


Figure 6: Drum mounting method

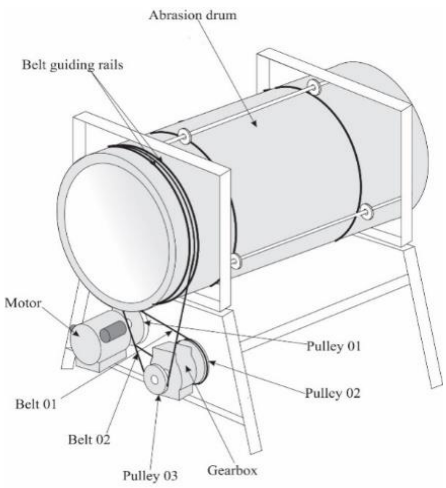


Figure 7: Power unit

- **Designing of Water spraying unit**

Raw potatoes frequently contain a plenty of microorganisms which are often led to food-borne outbreaks. Therefore, microbiological safety of food was a critical factor to be considered to minimize consumer's risk. Moreover, preliminary experiments revealed that the abrasion peeling of potato with water was helped to increase the peeling efficiency. By considering the reasons, both peeling and washing operations were integrated into this machine. Thus, a perforated 12.5 mm in diameter PVC pipe was designed as water spraying unit and it was fixed longitudinally inside the upper area of the abrasion drum, above the fibre brushes to clean the pared surfaces of food materials. Water spraying unit was connected to tap through a hose (Figure 8).

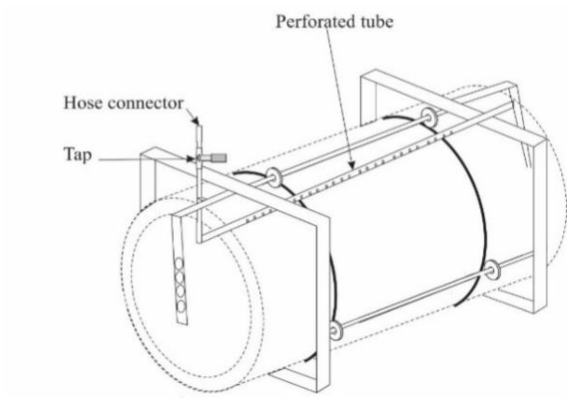


Figure 8: Water Spraying unit

- **Outlet and draining gutter**

The outlet was designed as a "U" shaped gutter which involved in conveying the peeled food products from peeling drum to collecting bin. The dimensions of the gutter were decided based on the diameter of the drum and bulk density of potato. The dimensions were length of 800 mm, width of 450 mm, and height of 70 mm, respectively. Considering Sri Lankan ergonomics, end of the outlet was designed at above 450 mm from the bottom of the main frame's legs [15]. Drain gutter was designed to collect washout just below the end part of the outlet (Figure 9).

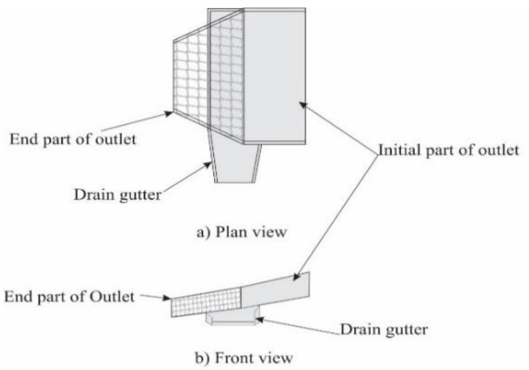


Figure 9: a) Plan view and b) front view of outlet and drain gutter

2.4 Material selection

In the materials selection stage, standard, durable, economical, and readily available materials were selected whenever possible to facilitate the repairs and maintenance at local workshops. The summary of the material selection and criteria are shown in the Table 1.

Table 1: Material and selection criteria for machine component

Component	**Selected material**	**Criteria**
Feeder	Amano sheets	Corrosion resistance, low cost, Workability.
Abrasion inner surface	Stainless steel	Corrosion resistance, food safety
Outer drum	Galvanized metal sheets	Corrosion resistance, low cost, workability.
Bearing drive shaft	Mild steel shaft	Workability, wear, resistance, strength
Set of brushes	Fibre brushes	Workability, wear, resistance, food safety, strength.
outlet	Stainless steel Plastic coated mild steel mesh	Corrosion resistance, workability, food safety.
Draining gutter	Amano sheets	Corrosion resistance, low cost, Workability
Frame	Mild steel L iron bars	Workability, strength, low cost,

2.5 Evaluation of the machine performance

Performance of the machine was compared with the manual peeling method. Samples of the most cultivated four-month-old *Granola* variety of potato were randomly selected for the experiment and comparisons were done separately for each type of peeling.

- **Manual peeling with Potato**

Traditionally, manual peeling was done by the means of an appropriately sharped knife, its blade was applied high pressure in between boundary of the peel and flesh, because of it, the peel removes from the flesh [16]. The potato samples were screened for damages. Each experiment was carried out in five times (5 kg).

- **Mechanical peeling with potato**

The machine was set for the experiment. The *Granola* variety of potato sample (5 kg) was loaded into the feeder hopper while the flow control gate should be at OFF state. Then the switch of the motor and tap of the spraying unit was ON. Food sample was released into the rotating abrasion drum by opening flow control gate to progress the mechanical peeling. Peeled food material was collected into collecting bin through the outlet while washout was collected through draining gutter into a separate bucket. Motor tap and flow control gate was off at the end of the peeling process.

The average values of below-mentioned parameters i.e., ambient weather conditions (air temperature, relative humidity), time taken to peel one kilogram of potato without considering any time losses (min), time taken to peel five kilograms of potato considering time losses (min), the mass of pared potato just after gently wipe them with blotting papers (kg), the amount of damaged potatoes (kg), were recorded for both peeling methods.

The dependent variables i.e., theoretical peeling capacity, actual peeling capacity, mechanical efficiency, peeling efficiency, average weight loss of peeled food material and damage percentage were calculated based on the recorded parameters, using equations [02], [03] [04],[05]and [06] for both peeling methods.

- **Theoretical peeling capacity:**

The average time taken to peel one kilogram of food sample without considering time wastage was used to determine the theoretical peeling capacity. Following equation was used to calculate the theoretical peeling capacity.

$$\text{Theoretical peeling capacity}\left(\frac{\text{kg}}{\text{h}}\right) = \frac{60\ min/h}{Time\ taken\ to\ peeled\ 1\ kg\ of\ food\ material\ (\frac{min}{kg})} \quad \text{[02]}$$

- **Actual peeling capacity:**

Considering the time wastage for loading, unloading, adjustments and resting, the actual amount of peel food material within one hour was considered as the actual peeling capacity.

- **Mechanical efficiency:**

The ratio between the actual and theoretical capacities of peeling methods results in the mechanical peeling efficiency [17].

$$Mechanical\ Efficiency = \frac{Actual\ peeling\ Capacity}{Theoritical\ Peeling\ Capacity} \times 100\% \quad \text{[03]}$$

- **Peeling Efficiency**

The percentage of the mass collected through peeler outlet to total mass of peel was the peeling efficiency of potato [18].

$$Peeling\ Efficiency\ (\eta) = \frac{Mpo}{Mpo + Mpr} \times 100\% \quad \text{[04]}$$

where: *Mpo* = Mass of peel collected through the peel outlet of the machine (kg), *Mpr* = Mass of peel removed by hand after machine peeling (kg).

- **Average weight loss of peeled food material:**

The mass of the raw food sample was measured before peeling and mass of pared food sample was measured immediately after removing water from the pared surface using lab blotting papers. Following equation was used to calculate the percentage peel losses [19].

$$\text{Percentage peel losses} = \frac{\text{Weight of raw food material} - \text{Weight of peeled food material}}{weight\ of\ raw\ food\ material} \times 100\ \% \quad \text{[05]}$$

- **Damage percentage:**

The ratio between the amount of damaged food material to the total pared food sample was the faction of damage food [19].

$$\text{Damage percentage} = \frac{Amount\ of\ Damaged\ Pared\ Food\ material}{Total\ amount\ of\ pared\ food\ material} \times 100\% \quad \text{[06]}$$

The comparison of dependent variables of manual and mechanical peeling was investigated using one sample t- test at significance level of P < 0.05.

- **Determination of appropriate horizontal inclination for the drum with potato**

The potato samples (5 kg) were fed into the drum for the experiment. Three different drum horizontal inclinations; A_1- 10°, A_2- 15°, A_1- 20° were used as treatments. Each experiment was carried out in triplicate and average values of following parameters; time taken to peel one kilogram of potatoes without considering any time losses (min), time taken to peel five kilograms of potatoes considering time losses (min), the mass of pared potatoes just after gently wiping them with blotting papers (kg), the mass of damaged potatoes (kg), and volume of water collected at the end of each batch were recorded. Then aforementioned parameters were used to calculate following dependent variables i.e., peeling efficiency, Percentage mass loss of peeled potato and damage percentage. The equations 03, 04 and 05 were used to calculate the dependent variables. Significant difference between treatments were investigated using one-way ANOVA at P < 0.05 significance level. Mean separations were done by Tukey's method ($P < 0.05$).

2.6 Cost of peeling comparison

To assess and compare the peeling costs of both manual and new mechanical method, all the cost of wages in manual and the fixed & variable costs in mechanical method were calculated. Furthermore, depreciation cost, interest, insurance, tax, housing, repair & maintenance cost were the fixed cost component and cost for electricity & lubricant and operator cost were variable cost component for mechanical peeling method where insurance and taxes have been assumed to be negligible for the machine. Mean annual depreciation cost was determined from the straight-line method [20] by equation 07.

$$Depreciation = \frac{P - S}{N} \quad \text{[07]}$$

Where; P = Purchase price, S = Salvage price (10% of purchase price) [21], N = Total life in years (10 Years)

Interest of actual cost in the machine was determined from the straight-line method [21] by Equation 08.

$$Interest = \frac{P+S}{2} \times \frac{r}{100} \quad \text{[08]}$$

Where; r = Present interest rate per annum

The cost for housing, repair and maintenance were 1.5% and 8%, respectively, of purchase value and were calculated from equation 09 and 10.

$$Housing = P \times \frac{h}{100} \quad \text{[09]}$$

Where; h = housing rate

$$Repair\ and\ Maintenance = P \times \frac{m}{100} \quad \text{[10]}$$

Where; m = Repair and maintenance rate

Then, the hourly fixed cost was calculated as equation 11 [21].

$$Hourly\ Fixed\ Cost = \frac{Annual\ Fixed\ Cost}{Operating\ Hours\ per\ year} \quad \text{[11]}$$

Annual operation of the machine has been considered as 3000 hours based on a maximum of 300 days per year (daily 10 h) of actual use of potato peeling.

Variable costs occupied cost for electricity & lubricant and operator cost; those costs are directly related to the amount of work done by the machine. Electricity cost was calculated according to the procedure of the Ceylon Electricity Board. Labour charge has been considered as per the prevailing rate (LKR.1500/=) per day (10 h work). The lubrication charge has been assumed as 5% of the cost of electricity [21].

- **Determination of Break-even Point**

The number of kilograms of food material required to be peeled per year to justify the ownership of the machine was determined by calculating the break-even point using the following equation 12 [21]

$$B_e = \frac{F_c}{V_{ct} - V_m} \quad \text{[12]}$$

Where; B_e = Break-even point (kg yr^{-1}), F_c = Fixed costs (Rs. yr^{-1}), V_{ct}= Variable costs for manual method (Rs. kg^{-1}), V_m= Variable costs for machinery method (Rs. kg^{-1}).

3. Results and Discussion

3.1 Preliminary experiments for determination of machine design parameters

Preliminary experiments were carried out to find the length, width, thickness, bulk density, and angle of repose of the unpeeled potato to determine the capacity of feeder hopper, abrasion drum and angle of slope of the feeder hopper, respectively. Table 2 shows the descriptive statistics for the measured physical parameters of potato.

The length of the selected potato ranged from 112.78 mm to 42.03 mm with the mean of 79.47 mm and coefficient of variance (CV) of 25.22%. Besides, the width of the selected potato was 67.78 mm to 34.62 mm with the mean of 52.38 mm and CV of 16.91%. Moreover, the thickness of the selected potato ranged from 59.87 mm to 28.15 mm with the mean of 44.95 mm and CV of 14.92%. Further the measured parameter of potato i.e., the length, width and thickness of potato revealed moderate variability (>35%) according to the classification of CV [22].

The equivalent diameter, Surface area and sphericity of the potato samples were calculated based on the measured physical parameters. The descriptive statistics of calculated physical parameters of potato are shown in Table 3.

The equivalent diameter of the selected potato ranged from 76.49 mm to 34.52 mm with the mean of 56.94 mm and coefficient of variance of 18.42%. Furthermore, the surface area of the selected potato was 16960.35 mm^2 to 3741.18 mm^2 with the mean of 10526.05 mm^2 and coefficient of variance of 34.21%. Besides, the sphericity of the selected potato ranged from 0.73 to 0.61 with the mean of 0.68and coefficient of variance of 3.97%. The results highlighted those calculated parameters of potato i.e., the equivalent diameter, surface area and sphericity of potato had moderate variability (>35%) according to the classification of CV [23].

Table 2: Descriptive statistics of measured physical parameters of potato

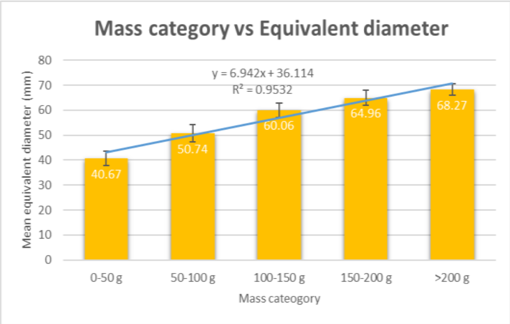
Mass category	Parameters (mm)	Mean value	Maximum	Minimum	SD	CV (%)
a-0-50 g	Length	48.05	55.64	42.03	±3.41	7.09
b-50-100 g		67.39	75.29	57.69	±5.43	8.05
c-100-150 g		88.40	100.29	74.52	±8.57	9.69
d-150-200g		93.45	100.03	80.75	±4.54	4.85
e->200 g		100.08	112.78	88.81	±5.83	5.82
a-0-50 g	Width	40.20	46.97	34.62	±3.24	8.05
b-50-100 g		47.02	52.49	39.11	±3.59	7.63
c-100-150 g		53.21	62.39	47.32	±3.94	7.40
d-150-200g		58.70	67.78	51.42	±3.60	6.13
e->200 g		62.99	67.33	58.73	±2.24	3.55
a-0-50 g	Thickness	35.29	40.38	28.15	±3.58	10.14
b-50-100 g		41.32	49.37	36.02	±3.24	7.90
c-100-150 g		46.33	50.26	39.57	±2.96	6.38
d-150-200g		50.13	59.87	42.90	±4.06	8.09
e->200 g		50.58	55.75	46.07	±2.57	5.08

SD- standard deviation, CV- coefficient of variance

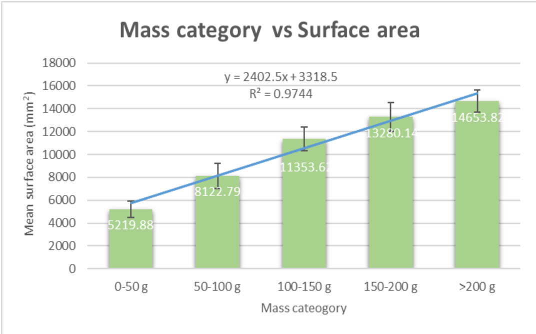
Table 3: Descriptive statistics of calculated physical parameters of potato

Mass category	Parameters	Mean value	Maximum	Minimum	SD	CV (%)
a-0-50 g	Equivalent diameter	40.67	45.97	34.52	2.87	7.05
b-50-100 g		50.74	56.83	44.10	3.48	6.85
c-100-150 g		60.06	64.51	51.87	2.82	4.69
d-150-200g		64.96	72.34	59.83	3.02	4.64
e->200 g		68.27	73.49	64.68	2.22	3.25
a-0-50 g	Surface area	5219.88		3741.18	726.14	13.91
b-50-100 g		8122.79	10139.56	6107.50	1104.46	13.59
c-100-150 g		11353.62	13067.15	8447.32	1042.24	9.02
d-150-200g		13280.14	16432.89	11240.95	1248.29	9.39
e->200 g		14653.82	16960.35	13138.19	966.22	6.59
a-0-50 g	Sphericity	0.84	0.92	0.75	0.04	4.76
b-50-100 g		0.75	0.84	0.70	0.03	4
c-100-150 g		0.68	0.77	0.60	0.05	7.35
d-150-200g		0.69	0.78	0.64	0.03	4.34
e->200 g		0.68	0.73	0.61	0.02	2.94

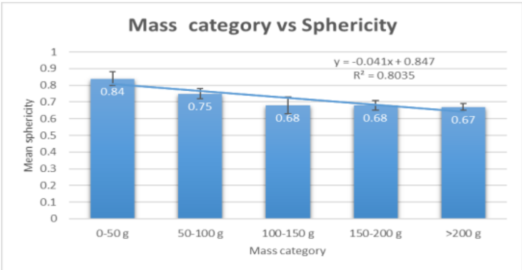
SD- standard deviation, CV- coefficient of variance



(a)



(b)



(c)

Figure 10: The relationship between the potato mass categories and mean values of calculated physical parameters (a) Mass category vs Equivalent diameter (b) Mass category vs Surface area (c) Mass category vs Sphericity. Error bars represent the standard deviations.

The relationship between the mass of potato vs means values of calculated physical parameters of potato (i.e., equivalent diameter, surface area, and sphericity) are illustrated in Figure 10 (a), 10 (b), and 10 (c), respectively.

Correlation analysis revealed the strong positive correlations (R^2>0.95) with mass categories of potato tuber vs. calculated mean values of equivalent diameter (Figure 10 (a) and mass categories of potato tuber vs surface area (Figure 10(b). Furthermore, a strong negative correlation (R^2=0.80) was observed between mass categories vs sphericities (Figure 10 (c)).

The angle of "repose is the steepest slope of the unconfined material, measured from the horizontal plane on which the material can be heaped without collapsing" [24, 25]. Calculations of the angle of repose were repeated twice for each selected potato sample. It was reported the ranged from 34° 33" to 31° 34" with the mean of 32° 43".

The experiment for the bulk density was repeated three times for each selected sample. it was revealed that the bulk density values ranged from 627.78 kg m^{-3} to 648.88 kg m^{-3} with the mean of 640 kg m^{-3}.

The machine components were designed based on the data collected from the preliminary experiment.

3.2 Machine Fabrication

Table 4 shows the specifications of the fabricated peeling machine.

Table 4: Specifications of the peeler

Parameter	Specifications
Height of the hopper	50 cm
The slant height of the hopper	52.2 cm
Dimensions of the upper base of the hopper	50 cm × 50 cm
Dimensions of the lower base of the hopper	20 cm × 20 cm
Type of flow control gate	Sliding gate
Cross-section dimensions of conveyer tube	20 cm × 20 cm
The bent angle of the conveyer tube	135˚
Diameter of the inner drum	38 cm
Diameter of the outer drum	40 cm
Length of the drum	125 cm
The capacity of the drum	10 kg while operating
Operating mode	Continuous type
Rotating speed	75 rpm
Electric motor Gearbox	Single-phase, Low speed, 1480 rpm, 2.2 kW 1/10 gear ratio

The machine was fabricated by combining four individual units i.e., feeder, rotary abrasion drum, water spraying unit, power unit and outlet and draining gutter. The power source was an electrical motor. Power transmission in the machine was accomplished through belts and pulleys. Plates 1,2,3,4 show the fabricated abrasion drum type potato peeling machine.

Plate 1: Feeder of the peeler

Plate 2: Rotary abrasion drum

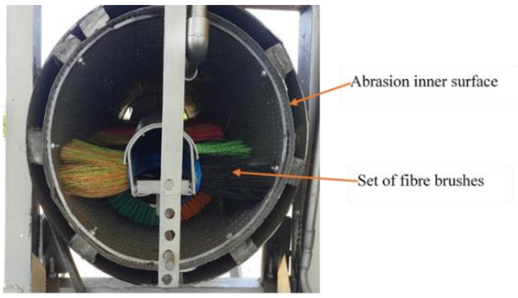


Plate 1: Inside of Rotary abrasion drum

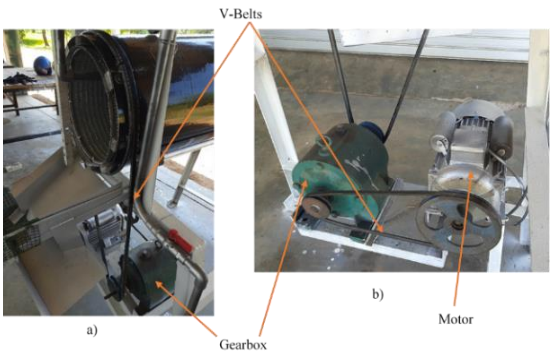


Plate 2: Power and transmission unit

3.3 Performance Evaluation of the Machine

The performance of the machine was evaluated compared to the manual peeling method. Mean actual capacities of manual peeling and mechanical peeling were 6.86 kg h^{-1} (SD±1.43), and 118.41 kgh^{-1} (SD±0.07), respectively. Five trials were carried out to minimize the errors. Manual peeling and mechanical peeling methods were compared with the one-sample t-test. It has been shown that there is a significant difference between the manual method and the mechanical method ($p<0.05$). In the manual method, the operator must manually apply pressure on the peel of the potato by a blade of sharpen knife. However, peeling was performed by the combination of rotary abrasion surface and two sets of fibre brushes in the mechanical process. Therefore, the peeling process in the machine was too easy than the manual peeling. Figure 11 shows the theoretical capacities and actual capacities of manual and mechanical peeling methods.

The mechanical peeling process is a continuous process so that improperly peeled potatoes can be fed into the machine without disturbing the peeling process. In contrast, it was required to peel completely at once in manual peeling while consuming more time with the hand tools. Therefore, manual peeling has shown a significant difference with lower capacity ($p<0.05$).

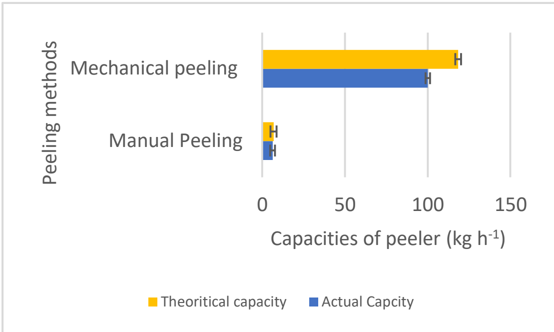


Figure 11: Theoretical capacities & Actual capacities of manual and Mechanical peeling of potato. Error bars represent the Stranded deviations. Horizontal bars with different letters are significantly different treatments.

The mean mechanical efficiencies of manual peeling and the mechanical peeling methods were 92.67% ±0.29 and 84.50% ±0.09, respectively. The results of the one-sample t-test showed that the mechanical peeling was significant lower in comparison to manual peeling ($p<0.05$) as Figure 12. As mechanical peeling is a continuous power operating process, time wastage for the loading raw material, adjustment of the machine took more time than those of the manual peeling. Therefore, mechanical peeling has shown a lower efficiency in comparison to manual peeling.

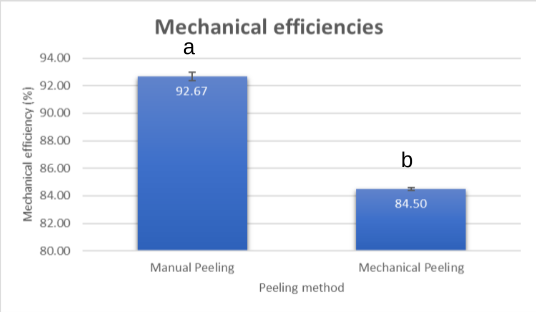


Figure 12: Mechanical Peeling efficiencies of Manual and mechanical peeling method. Error bars represent the Stranded deviations. Vertical bars with different letters are significantly different treatments.

- **Determination of appropriate horizontal inclination for the drum with potato**

The peeling efficiency of the mechanical peeling method was tested with three different drum horizontal angles (10°, 15° and 20°).Mean peeling efficiencies of the mechanical peeling were 87.57% (SD± 0.98), 82.71% (SD± 0.26) and 78.08% (SD± 0.88) at the peeling drum horizontal angles of 10˚, 15˚ and 20˚ respectively. Analysis of variance (ANOVA) revealed that the treatment effect was significant ($p<0.05$). Moreover, the Tukey's mean separation procedure results revealed significant differences among each treatment ($p<0.05$). Figure 13 graphically shows the peeling efficiency vs horizontal drum angles.

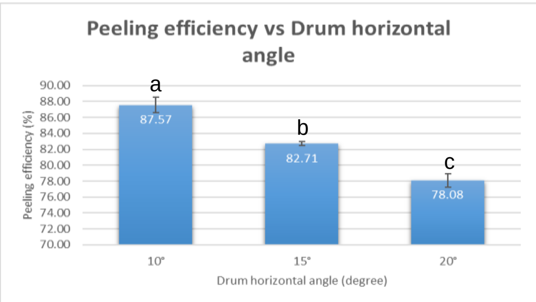


Figure 13: Peeling efficiency vs Drum horizontal angle. Error bars represent the stranded deviation. Vertical bars with different letters are significantly different treatments.

The mean percentage mass loss of mechanical peeling at the 10°, 15°, and 20° drum horizontal angles were 3.58% (SD±0.06), 3.56% (SD±0.04), and 3.57% (SD±0.03) shown in Figure 14. ANOVA revealed that there was not significant difference among treatment of peeling loss in the mechanical method. Therefore, it can be optimized that the most appropriate horizontal drum angle for the drum is 10° with 75 rpm of rotating speed.

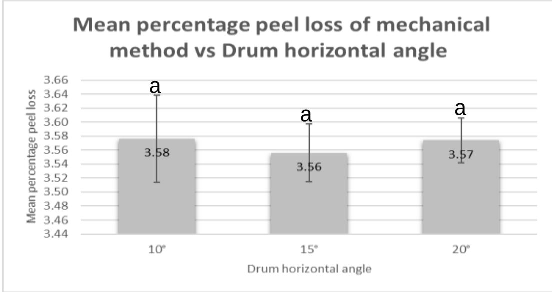


Figure 14: Mean percentage peel loss of mechanical method vs Horizontal drum angle. Error bars represent Stranded deviation. Vertical bars with different letters are significantly different treatments.

The highest mean percentage peel loss was reported for manual peeling (4.34%±0.03) (Figure 15). ANOVA revealed that the treatment effect was significant ($p<0.05$) and the Tukey's mean separation procedure showed a significant difference between each manual and mechanical methods ($p<0.05$). While peeling the potato tubers manually, undulated areas of potato tubers are cut by the hand tool. However, undulated surfaces were peeled by a set of fibre brushes in the mechanical peeling. The percentage of mass loss was comparatively lower in manual peeing in comparison to mechanical peeling.

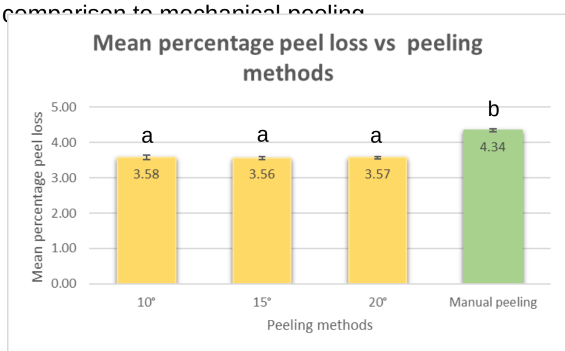


Figure 15: Mean percentage peel loss vs peeling methods. Error bars represent the stranded deviation. Vertical bars with different letters are significantly different treatments.

The mean damage percentages of mechanical and manual peeling were 4.24%±1.52, and 0.84%±1.15. Furthermore, one-sample t-test revealed a significant difference in damage percentage between manual peeling and mechanical peeling methods ($p<0.05$). Since mechanical peeling is a continuous mechanical process, clogging of potato can occur inside the peeling drum at the initial point of the food introducing into the peeling drum. Therefore, it causes for having damages to the tubers. In manual peeling, the process is frequently done under the supervision of the operator manually. Therefore, damage percentage was comparatively lower in manual peeing in comparison to mechanical peeling.

- **Cost of peeling comparison**

Manual peeling method was occupied only labour cost as variable cost component as well as total cost. However, the mechanical peeling has fixed and variable cost components. The calculations of the total peeling cost of peeling methods and composition of fixed and variable cost are illustrated in Table 5.

Table 5: Calculations for the total peeling cost for manual and mechanical methods

Case	New Mechanical peeling method	Manual peeling method
Purchase value (Rs.)	60,000.00	-
Machine life (yr)	7	-
Annual use (h)	3000.00	-
Salvage value (Rs.)	6000.00	-
Fixed costs		
Depreciation (Rs. yr^{-1})	7715.00	-
Interest (Rs. yr^{-1})	3300.00	-
Shelter (Rs. yr^{-1})	900.00	-
Repair & maintenance (Rs. yr^{-1})	4800.00	-
Annual fixed cost (Rs. yr^{-1})	16715.00	-
Hourly fixed cost (Rs. h^{-1})	5.57	-
Variable costs (Rs. h^{-1})		
Electricity	15	-
Lubrication	1.5	-
Labour	187.50	187.5
Total variable cost	204.00	187.5
Total peeling cost (Rs. h^{-1})	209.60	187.5
Total peeling cost (Rs. kg^{-1})	2.09	29.52
Effective field capacity (kg h^{-1})	100.03	6.35
Electricity consumption (kJ h^{-1})	5400	-

The total peeling cost per hour for the manual and mechanical method was LKR. 187.50 and LKR. 209.60. Nevertheless, when comparing the total cost for peel one kilogram of potato, it was accounted LKR. 2.09 cost for mechanical method while the manual method reported LKR. 29.52 per kg. High capacity of the mechanical peeling method was the reason for the low total cost per kilogram of potato in comparison to the manual peeling method.

The break-even point is the number of kilograms that a machine must peel per year to justify owning the peeling machine [22]. According to the obtained results for the comparative performance evaluation, the newly designed peeler reported a moderately higher break-even point value, and it is appropriate for medium and large-scale food processors who have annual potato-based processed production of more than 608 kg.

4. Conclusion

The performances of two peeling methods were showed both strengths and limitations. However, the newly designed peeler displayed superior performance in peeling capacity (which is 15 times higher than the manual method), peeling efficiency, higher performances in cost of peeling (92.92% cost reduction with manual peeling) and satisfactory performance in damaged percentage in comparison to manual peeling method. Besides, it shows the significantly lowest percentage peel loss (less than 4%) which leads to minimizing post-harvest losses. The cost of operation and the labour requirement for the newly designed peeler were $1/14^{th}$ and $1/15^{th}$ to the conventional manual peeling, respectively.

Further, this peeler showed comparatively lower electricity consumption, repair & maintenance, and lubrication cost as percentages from annual cost i.e., 7%, 1% and 1%, respectively. Since the break-even point of this machine was moderate higher (608 kg yr^{-1}). It is appropriate for medium and large-scale food processors.

Moreover, the newly designed peeling machine reported higher satisfactory performances in practical tests i.e., 100.05 $kgh^{-1}$of actual peeling capacity, 84.50 % of mechanical efficiency, 87.57%of peeling efficiency, 4.24% of damaged food percentage and 3.58% of peeling loss. Further, the calculated cost for peeling one kilogram of potato was LKR. 2.09. Calculated electricity consumption and labour were 5400 kJh^{-1}, one person respectively without machine breakdown throughout the test. Thus, it can be concluded that a newly designed abrasion type continuous peeling machine could be introduced as an appropriate solution for the peeling process of medium and large-scale food processors in Sri Lanka.

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