Research Article

Design, Development and Performance Evaluation of an Abrasion Peeling Machine for Ambarella (*Spondias dulcis*) fruits

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Abstract: Ambarella (*Spondias dulcis*) is one of the newest exotic fruits to gain popularity since it has been used to produce various processed food in Sri Lanka. The fruit pulp of Ambarella is the primary entity used to process food. Thus, peeling at the preliminary processing stage is required to obtain fruit pulp. Currently, it has been done manually using hand tools, which takes a lot of time and labour costs. In addition, no technical solution has been developed for the small and medium food processing industry. Consequently, a continuous type, rotary abrasion peeling cum washing peeler was fabricated as a solution for Ambarella peeling to satisfy food processing at micro, small and medium enterprises (MSMEs). The machine consists of an abrasion drum where a fibre brush roller and water spraying unit are incorporated. While the drum spins, peeling is performed by a combination of abrasion surface, brush roller and water. The comparative machine performance was evaluated to find the best suited horizontal drum angle for peeling of Large and Miniature fruit types of Ambarella and compared with the manual knife peeling method. The best suited horizontal drum angle and rpm for mechanical Ambarella peeling were 10° and 75 rpm, respectively. At this point, the machine capacity was 102 kg/h, with 49% peeling efficiency regardless of Ambarella fruit types. Moreover, the new peeling machine showed significantly higher (22-fold) mechanical peeling capacity in comparison to knife peeling ($p < 0.05$). However, machine peeling efficiency was significantly lower than manual knife peeling ($p < 0.05$). Furthermore, the material loss was less than 5%. The costs of peeling the Ambarella by machine and manual process were 2.00 LKR/kg and 40.00 LKR/kg, respectively. Machine peeling necessitates 19 times less labour than manual peeling. Based on the machine capacity, it is appropriate for MSMEs. However, further improvements are needed to enhance the Ambarella peeling efficiency.

Keywords: Abrasion peeling, Actual capacity, Ambarella peeling, Fibre brushes, Peeling efficiency.

1. Introduction

Ambarella (*Spondias dulcis*) has been categorized as an underutilized and seasonal fruit in Sri Lanka. However, it is one of the new exotic fruits that has quickly gained popularity (Ranathunga et al., 2011). Tall local stain (Large fruit type) and dwarf introduction (Miniature fruit type) are the two verities available in Sri Lanka (Department of Agriculture Sri Lanka, 2015). Ambarella is cultivated throughout the country regardless of the differences in agro-climatic zones as small acreages or home gardens under cultivation and is not classified as a plantation crop (Mohammed et al., 2017). Harvest can be obtained year-round from dwarf cultivars and from July to August from tall cultivars (Department of Agriculture Sri Lanka, 2015). Ambarella fruits can be eaten fresh because their flesh is crunchy and slightly sour. Further, Ambarella fruits are widely processed as curry, chutney, and pickle at the household level in Sri Lanka (Jana, 2016).

Natural components of the Ambarella fruit include water, sugars, organic acids, and flavour compounds, which all contribute to the overall flavour and consistency of the processed product (Minh and Oanh, 2018). Sub-

sequently, there is a rising trend to produce various value-added products such as minimally processed products, pickles, salads, fruit nectar and beverages as street snacks and chutney, jam, and a stew as preserved products for the supermarket by both popular food processing industries and micro, small and medium enterprises (MSMEs) food processers in Sri Lanka. The pulp of the Ambarella fruit is used to formulate the most processed value-added products. Thus, as the first unit operation, the outer skin must be peeled to obtain the pulp from the fruits (Ranathunga et al., 2011; Daranagama et al., 2012). The type of product determines the rest of the unit operations. As a result, the Ambarella fruit peeling technique is being studied.

Peeling methods for fruits and vegetables are generally classified as thermal, chemical, and mechanical peeling. Thermal peeling is commonly used on tough or thick-skinned fruits and vegetables (Pumpkin and Melon) which uses heat, pressure, and electronic devices to crack the outer skin into small pieces. Chemical peeling loosens and removes the outer skin of fruits and vegetables by soaking them in a caustic NaOH (Lye) solution. However, it has several drawbacks, including a high cost for NaOH solution, quality loss due to chem-
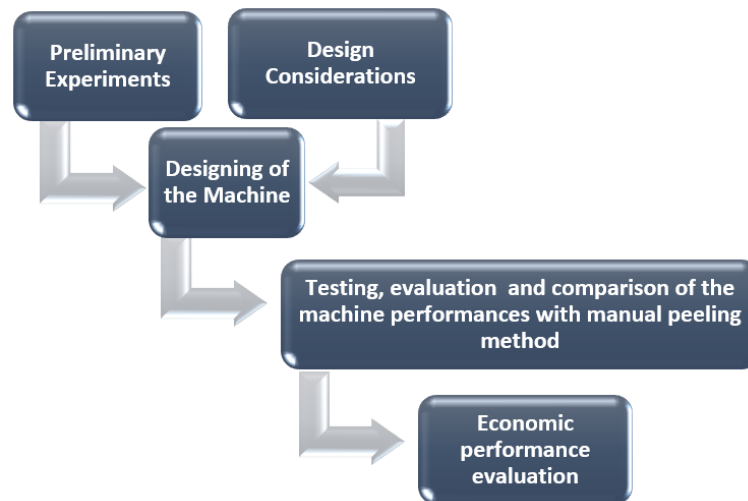
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Figure 1: The steps carried out in this experiment

ical reactions, and the inability to remove trace chemicals that can be poisonous (Talodhikar et al., 2017). Manual peeling with simple hand tools is viable for any fruit or vegetable. However, it has significant drawbacks such as counting high peeling loss, high time and labour requirements, and contamination by ambient air. Consequently, mechanical peeling has become the preferred method among processors (Emadi, 2005; Gaodi et al., 2017).

In food processing, Sri Lankans frequently use manual peeling for fruits at micro, small, and medium enterprises (MSMEs) and commercial levels. Increased physical drudgery, significant peeling losses, and poor hygiene are all linked to this time and labour-intensive manual peeling process. Although imported peeling machines have recently been used to automate this process, they have limitations. They do not meet the needs of the Sri Lankan food processing industry, owing to high initial costs, high peeling losses, low peeling efficiency, and machine conformity to a single purpose. On the other hand, labour scarcity and cost have created issues, especially in MSMEs' food sector. Based on the above facts, this study aims to develop a horizontal continuous rotary drum abrasion peeling machine to remove the outer skin of Ambarella to facilitate the Sri Lankan food industry.

2. Methodology

The steps followed to achieve the study's objectives are shown in Figure 1.

2.1. Preliminary Experiments for the Determination of Machine Design Parameters

The preliminary tests were conducted to determine the optimal dimensions of the machine in terms of saving material, time, and cost (Shirmohammadi et al., 2011). The size and shape of the machine components were determined based on the physical properties of well-

matured Ambarella fruits (Large and Miniature types). Subsequently, Ambarella fruits were screened for damages, and basic geometric characteristics such as length, width, thickness, equivalent diameter, and mass were determined. A digital Venire calliper was utilized to measure the length, width, and thickness of Ambarella fruits (Large and Miniature types). The equivalent diameter (D_{eq}) was calculated using Equation (1).

$$D_{eq} = \sqrt[3]{L \times W \times T} \tag{1}$$

where L is the length, W is the width and T is the thickness.

The mass of Ambarella fruits was determined using a top-loading balance. Surface area, sphericity, bulk density, and angle of repose were determined as complex geometric characteristics. The bulk density (ρ_b) was calculated according to Mohsenin (1970) as explained by Cruz-Matias et al. (2019) by the mass-volume relationship by filling an empty plastic container of predetermined volume ($4500\ cm^3$) with samples and weighing it, later dividing the mass of the samples by the container volume. The surface area (S), sphericity (ϕ), and bulk density (ρ_b) were calculated using the Equations (2), (3) and (4), respectively (Mohsenin, 1970; Yurtlu et al., 2010; Dalvand, 2011; Cruz-Matias et al., 2019).

$$S = \pi D_{eq}^2 \tag{2}$$

$$\phi = \frac{D_{eq}}{L} \tag{3}$$

$$\rho_b = \frac{M_f}{V_c} \tag{4}$$

where M_f is the mass of food materials and V_c is the volume of the container.

The angle of repose of Ambarella fruits was determined according to Ismail (1988) by the fixed funnel method.

2.2. Design Considerations

The machine was designed based on the following considerations to achieve high efficiency and reliability: capable of peeling different Ambarella varieties, shapes and sizes, made from readily available materials, decreased labour input in conventional Ambarella peeling methods, and high capacity compared to manual operations, cost-effective and within the purchasing power of local farmers.

2.3. Machine Description

Mechanical peeling of Ambarella is a series of unit operations which includes feeding raw Ambarella into a peeling mechanism, separating inedible outer skin from edible fleshy, washing peeled food to achieve a cleaner and hygienic product, and collecting peeled food separately from residuals. Therefore, the abrasion peeling machine was made by assembling five separate units: a feeding hopper, abrasion drum, water spraying unit, outlet and draining gutter to comply with the above unite operations. Unpeeled Ambarella fruits were directed into the abrasion drum through the feeding hopper under gravity. The abrasion drum consisted of double walls where protrusions were made on the inner drum wall to provide an abrasion surface for Ambarella fruit peeling. The protrusion size was $4mm \times 1mm$ in length and width, respectively and 36 protrusions per 8 cm^2. The drum's outer wall was smooth, which was mounted externally on the three sets of bearing drive shafts with 120° of the angle between each. Dimensions of the drum were 400 mm in diameter on the outer wall, 340 mm in diameter on the inner wall, and 1500 mm in length, respectively. A brush roller made of polypropylene (PP) fibres (length - 3.81 cm) was placed inside the abrasion drum to avoid food material moving along the drum wall without rubbing against it. In addition, the brush roller rotates opposite direction to the drum. Therefore, undulated surfaces of food materials peel off well by increasing the peeling efficiency. Furthermore, the drum and frame were designed so that the horizontal inclination towards the outlet could be adjusted using a screw drive mechanism on the front side and hinges on the backside of the drum.

A water spraying unit was installed lengthwise inside the abrasion drum above the fibre brush roller. This aided in cleaning the pared Ambarella while improving peeling efficiency.

A 3 HP single phase electric motor powered the abrasion drum. Based on the preliminary experiments, 70 RPM was determined to be the optimum drum speed for Ambarella peeling. The rotary motion of the abrasion drum helps to peel Ambarella fruits. Simultaneously, the fibre brush roller smoothly performs the peeling of Ambarella's undulate surfaces and directs them towards the outlet. Pared cleaned Ambarella collected by the outlet while draining gutter facilitates to discard the washout with the loose skin.

2.4. Evaluation of the Machine Performance

The performance of the machine was compared with the manual peeling method. Ambarella fruits (Large and Miniature types) were selected as raw materials, and comparisons were made separately for each fruit type.

2.5. Testing of Manual Peeling Parameters of Ambarella

Freshly harvested large and miniature types of Ambarella were used as samples for the experiment. All samples were screened for damages, and fruit samples of 5 kg were peeled separately by an appropriately sharpened knife with skilled operators. The test was replicated thrice, and Theoretical peeling capacity(PC_T), mechanical efficiency, peeling efficiency (PE), percentage mass loss (PMC) of peeled fruits and damage percentage(DP) were calculated using Equations (5), (6), (7),(8) and (9), respectively. The theoretical peeling capacity was calculated using the average time taken to peel one kilogram of food sample without accounting for time waste (Kosgollegedara et al., 2021).

$$PC_T = \frac{60 \ min/h}{t_{p1kg}} \qquad (5)$$

where t_{p1kg} is the time taken to peel 1 kg of food material (min/kg).

The actual peeling capacity (PC_A) was the actual amount of peel food material within one hour by considering the time wasted for loading, unloading, adjustments, and resting. The mechanical efficiency was calculated as the ratio between the actual and theoretical capacities of peeling methods (Singh and Shukla, 1995).

$$\text{Mechanical efficiency} = \frac{PC_A}{PC_T} \times 100\% \qquad (6)$$

The peeling efficiency of Ambarella was calculated as a percentage of the mass collected through the peeler outlet to the total mass of peel (Olayanju et al., 2019).

$$\text{Peeling Efficiency}(\eta) = \frac{M_{po}}{M_{po} + M_{pr}} \times 100\% \qquad (7)$$

where, M_{po} is the mass of peel collected through the peel outlet of the machine (kg) and M_{pr} is the mass of peel removed by hand after machine peeling (kg).

The mass of the raw food sample was measured before peeling, and the mass of the pared food sample was measured immediately after removing water from the pared surface using paper towels. The percentage peel losses were calculated using the following equation (Willard, 1971).

$$\text{Percentage mass losses} = \frac{M_r - M_p}{M_r} \times 100\% \qquad (8)$$

where M_r is the mass of raw food material and M_p is the mass of peeled food material.

The percentage of damaged food was calculated as the ratio of damaged food material to the total pared food sample (Singh and Shukla, 1995).

$$\text{Damage percentage} = \frac{PF_d}{PF_{Tol}} \times 100\% \qquad (9)$$

where PF_d is amount of damaged pared food material and PF_{Tol} is the total amount of pared food material.

2.6. Testing of Mechanical Peeling Parameters of Ambarella

Damage-free freshly harvested large type and miniature type of Ambarella (5 kg) were fed into the drum separately for the experiment. Three different drum inclinations, A1-10°, A2-15°, and A3-20°, were used as treatments. Three replications were performed for each treatment. The theoretical peeling capacities, Actual peeling capacity, mechanical efficiency, peeling efficiency, percentage mass loss of peeled fruits and damage percentage were calculated using the Equations (5), (6), (7), (8) and (9), respectively, for above data. This study used two fruit types (Large and Miniature type) and three horizontal drum angles (A1-10°, A2-15°, A3-20°). Hence, there were six fruit-type – horizontal drum angle combinations. These six combinations were used as the treatments in this study. The significant differences of the selected dependent variables (i.e., actual peeling capacity, theoretical peeling capacity, mechanical efficiency, peeling efficiency, percentage mass loss and damage percentage) under these treatments were statistically compared using one-way ANOVA. The experimental design was CRD with three replicates. Mean separation was conducted using Tukey's test at 5% significance level. The best-suited horizontal drum angle for mechanical peeling of Ambarella was selected based on the above statistical analyses.

Performances of mechanical and manual Ambarella peeling were compared using an independent sample t-test at a 5% significance level. The best-suited horizontal drum angle selected based on the previous study was used for mechanical peeling in this study.

2.7. Economic performance evaluation

All wages in the manual method and fixed and variable costs in the mechanical method were calculated to evaluate and compare the peeling costs of both manual and new mechanical methods. The mean annual depreciation cost was calculated by the straight-line method (using Equation 10). (Kepner et al., 1982; RNAM, 1983).

$$\text{Depreciation} = \frac{P - S}{N} \qquad (10)$$

where P is the purchase price, S is the salvage price and N is the total life in years (10 Years).

The break-even point was calculated using Equation 11 to determine the number of kilograms of food material that had to be peeled per year to justify the machine's ownership (Alizadeh et al., 2007).

$$B_e = \frac{F_c}{V_{ct} - V_m} \qquad (11)$$

where B_e is the break-even point (kg/year), F_c is the fixed costs (LKR/year), V_{ct} is the variable costs for manual method (LKR/kg) and Vm is the variable costs for machinery method (LKR/kg).

3. Results and Discussions

3.1. Preliminary Experiments for the Determination of Machine Design Parameters

Results of some basic geometric characteristics of both fruit types of Ambarella (Large and Miniature type) are presented in Table 1. According to the results, the mean values of length, width, thickness, equivalent diameter, and mass of the Ambarella large fruit type were 64.79 mm, 50.84 mm, 48.48 mm, 54.23 mm, and 90.47 g, respectively. Based on these values, the basic geometric characteristics of the Ambarella miniature fruit type were lower.

Therefore, the miniature Ambarella fruits were the smaller food item. Fruits of both Ambarella varieties were more uniform in size with respect to the coefficient of variability CV values (less than 12%). However, the CV's of the mass of Ambarella goes up to 26%. Such variations may affect the peeling efficiency. Moreover, as Warrick and Nielsen (1980) reported, the coefficient of variance (CV%) values of basic geometric characteristics of Ambarella large and miniature types were lower than the 35%, thus indicating low, moderate variability.

The basic geometric characteristics of Ambarella were used to calculate the complex geometric characteristics such as surface area, sphericity, bulk density, and angle of repose. The descriptive statistics of the complex geometric characteristics of Ambarella are displayed in Table 2.

The sphericity is a physical property that expresses the characteristic shape of a solid object comparative to that of a sphere of similar volume (Mohsenin, 1970). This property is applicable to the mass transfer phenomenon (Burubai and Amber, 2014). The mean sphericity values of Ambarella large and miniature types were 0.83 and 0.82, respectively. Ambarella fruits are closer to a sphere based on the mean sphericity values. Thus, Ambarella fruits have a tendency to roll over in the rotating drum. These sphericity data of food items are helpful for hopper design and handling food materials.

Bulk density is the mass of a group of individual particles divided by the space occupied by the entire mass, including the air space (Burubai and Amber, 2014). The mean bulk density value for Ambarella large and miniature types was 720.16 kg/m^3 and 720.12 kg/m^3, respectively. Based on the results, the bulk densities were

Table 1: Descriptive Statistics of Basic Geometric Characteristics of Ambarella (Large and Miniature type)

Ambarella type	Parameters	Mean value	Maximum	Minimum	SD	CV (%)
	Length (mm)	64.79	83.81	54.62	5.49	8.47
	Width (mm)	50.84	61.37	44.37	4.48	8.81
Large	Thickness (mm)	48.48	59.38	42.22	4.08	8.84
	Equivalent diameter (mm)	54.23	67.34	47.46	4.36	8.03
	Mass (g)	90.47	167.00	62.21	22.56	24.93
	Length (mm)	52.26	56.73	46.37	3.95	7.55
	Width (mm)	40.33	48.67	32.11	4.82	11.95
Miniature	Thickness (mm)	37.98	42.95	30.29	3.83	8.60
	Equivalent diameter (mm)	43.08	48.20	35.62	4.16	11.67
	Mass (g)	44.49	57.69	23.78	11.17	25.78

SD- standard deviation, CV- coefficient of variance

Table 2: Descriptive Statistics of Complex Geometric Characteristics of Ambarella (Large and Miniature types)

Ambarella type	Parameters	Mean value	Maximum	Minimum	SD	CV (%)
	Surface area (mm^2)	9295.50	14240.47	7073.12	$\pm$ 1539.05	16.55
	Sphericity	0.83	0.92	0.77	$\pm$ 0.03	4.45
Large	Bulk density (kg/m^3)	720.16	721.47	718.13	$\pm$ 1.43	0.19
	Angle of repose (degree)	30°01'	30°10'	29°32'	$\pm$ 0°16'	0.89
	Surface area (mm^2)	5879.20	7294.18	3984.74	$\pm$ 1102.76	18.75
	Sphericity	0.82	0.85	0.77	$\pm$ 0.02	2.43
Miniature	Bulk density (kg/m^3)	720.12	720.93	719.33	$\pm$ 0.65	0.09
	Angle of repose (degree)	31°25'	32°35'	30°06'	$\pm$1°08'	3.59

SD- standard deviation, CV- coefficient of variance

Figure 2: Fabricated abrasion Ambarella peeling machine: 1-Feeding hopper, 2-Abrasion peeling drum, 3-Main frame, 4-Outlet, 5-Draining gutter, 6-Power transmission unit.

similar for both fruit types of Ambarella.

Furthermore, the mean values of angle of repose for Ambarella large and miniature types were 30°01' and 31°25'. This parameter was used to design the hopper's angle of slope.

3.2. Machine description

The machine was fabricated by combining five separate units: feeder, rotary abrasion drum, water spraying unit, power unit, and outlet and draining gutter. An electrical motor provided the power, and transmission was occupied with a gearbox, belt, and pulley system. Figure 2 shows the components of the newly developed peeler for Ambarella.
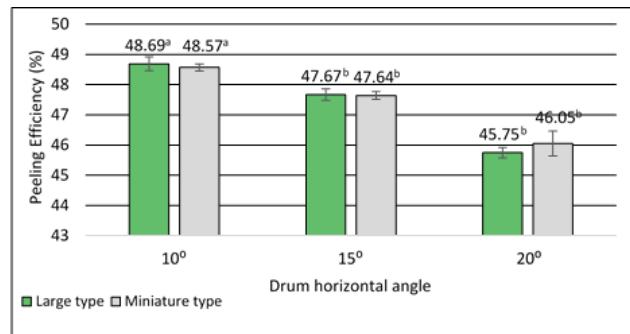
3.3. Evaluation of the Machine Performance

A comparative performance evaluation was conducted for Ambarella (large and miniature types). Based on the results in Table 3, Ambarella's theoretical and actual
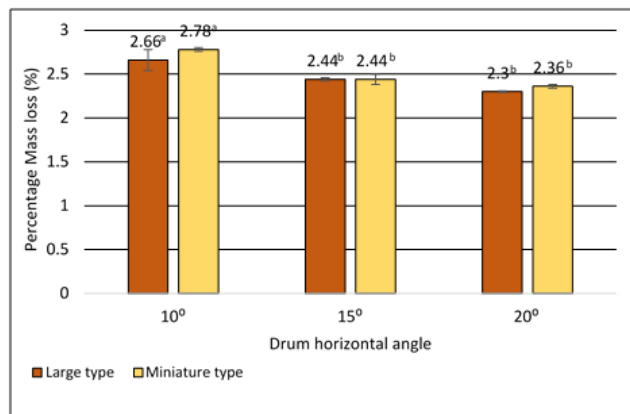
Table 3: Theoretical, Actual Peeling Capacities and Mechanical efficiencies of Mechanical Peeling of Ambarella

Ambarella type	Theoretical Peeling capacity			Actual peeling capacity			Mechanical efficiency %		
	Horizontal drum angle			Horizontal drum angle			Horizontal drum angle		
	10°	15°	20°	10°	15°	20°	10°	15°	20°
Large	123.2^a	123.3^a	124.1^b	102.2^a	102.6^a	103.3b	82.93^a	83.17^a	83.25^a
	(±0.1)	(±0.13)	(±0.41)	(±0.2)	(±0.1)	(±0.1)	(±0.25)	(±0.90)	(±0.16)
Miniature	123.2^a	123.2^a	123.9^b	102.3^a	102.8^a	103.4^b	83.01^a	83.39^a	83.42^a
	(±0.10)	(±0.02)	(±0.15)	(±0.1)	(±0.11)	(±0.20)	(±0.12)	(±0.12)	(±0.45)

Values with different characters are statistically significant ($p < 0.05$), and dependent variables were not statistically compared.

(a)

(b)

Figure 3: (a) The Peeling Efficiency and (b) Percentage Mass Loss of Mechanical Peeling of Ambarella

capacities in both varieties were significant ($p \leq 0.05$), along with the horizontal drum angles.

The significantly higher theoretical and actual capacities were reported for the Ambarella large (PC_T-124 kg/h, PC_A-103 kg/h) and miniature types (PC_T-123 kg/h, PC_A-103 kg/h) at the 20° of horizontal drum angles than those at the 10° and 15° drum angles. The reason is that a higher horizontal drum inclination at 20° facilitates significantly higher mass movement through the abrasion drum compared to the other angles. According to Kosgollegedara et al. (2021), the Actual peeling capacities for potatoes (Granola variety) with the same peeling machine at the 20° of horizontal drum angles were reported as 118.41 kg/h.

The mechanical efficiencies of Ambarella large and miniature types were insignificant ($p \geq 0.05$) with the horizontal drum angle. The reason is due to similar factors of time losses that were affected by the mechanical peeling on three different horizontal drum angles.

The peeling efficiencies of the mechanical method for Ambarella were significant ($p < 0.05$) among the three different horizontal drum angles regardless of the type of Ambarella (Figure 3). In comparison to the other two efficiencies at 15° and 20° horizontal drum angles, the peeling efficiency at 10° (49%) horizontal drum angle is significantly higher ($p < 0.05$). Furthermore, peeling efficiencies were insignificant at the 15° and 20° drum angles. The 10° horizontal drum angle may allow sufficient retention time for mechanical peeling of Ambarella irrespective of the type of fruits. Kosgolegedara et al. (2021) reported that the peeling efficiency for the potato Granola variety at 10° the horizontal drum angle was

Table 4: Performance Parameters of Mechanical Peeling Methods of Ambarella

Dependent variables	Peeling methods			
	Manual peeling		Mechanical peeling	
			Drum at $10°$ of horizontal angle	
	Large type	Miniature type	Large type	Miniature type
Theoretical capacity (kg/h)	5.22^a	5.18^a	123.27^b	123.27^b
	(±0.04)	(±0.01)	(±0.10)	(±0.10)
Actual capacity (kg/h)	4.74^a	4.63^a	102.22^b	102.33^b
	(±0.06)	(±0.03)	(±0.23)	(±0.12)
Mechanical efficiency (%)	90.73^a	89.28^a	82.93^b	83.01^b
	(±0.76)	(±0.98)	(±0.25)	(±0.12)
Peeling efficiency (%)	100^a	100^a	48.69^b	48.57^b
			(±0.02)	(±0.04)
Percentage mass loss (%)	6.36^a	6.43^a	2.66^b	2.78^b
	(±0.11)	(±0.09)	(±0.12)	(±0.02)
Food damage percentage (%)	-	-	3.54^a	3.43^a
			(±0.20)	(±0.12)

Values with different characters are statistically significant ($p < 0.05$), and dependent variables were not statistically compared.

88%.

In the mechanical peeling of Ambarella, the percentage mass losses (3%) were significant ($p < 0.05$) at the $10°$ horizontal drum angle despite fruit types , as shown in figure 3b. The reason is significantly higher peeling efficiency at $10°$ of horizontal drum angle compared to the other two drum angles. Moreover, the percentage mass loss for the potato Granola variety was 4.24% at $10°$ of horizontal drum angle (Kosgollegedara et al., 2021).

Based on the above-reported results holistically, the horizontal drum angle of $10°$ has been observed to be the best horizontal drum angle for the mechanical peeling of Ambarella.

3.4. Comparison of Manual and Mechanical Ambarella Peeling Methods

Skilled operators carried out the manual peeling for Ambarella large and miniature types with appropriately sharpened knives. Manual peeling results were compared to mechanical peeling results obtained at a horizontal drum angel at $10°$. The results of dependent variables of Ambarella manual and mechanical peeling are displayed in Table 4.

The actual and theoretical capacities of Ambarella peeling were significant ($p \leq 0.05$) among the peeling methods. Despite the fruit types, significantly greater actual and theoretical capacities were reported in the mechanical method compared to the manual method ($p \leq 0.05$). It may be due to the faster rotary abrasion mechanism than the manual knife peeling. The manual Ambarella peeling efficiency (100%) was significantly ($p \leq 0.05$) higher than the mechanical peeling. The Ambarella can be peeled entirely by applying the required force and better individual operator supervision during the manual peeling. Therefore, this results in higher peeling efficiencies in the manual method.

Percentage mass losses of the Ambarella peeling were significant in the manual peeling (6%) compared to the mechanical peeling of Ambarella, regardless of the types of fruits. This is because the manual peeling method completely removes the peel of individual Ambarella fruit more than the mechanical method.

The negligible food damage percentages for the manual peeling and food damage percentages in mechanical peeling of large and miniature types of Ambarella were 3.54 ± 0.20% and 3.43 ± 0.12%, respectively. The damage in machine peeling is mainly due to the jamming and clogging of fruits in the abrasion drum during peeling.

3.5. Economic performance evaluation

The total cost of peeling for one kilogram of Ambarella was LKR. 2.05 in the mechanical method, while in the manual method, it is increased to LKR 40.06, respectively. The greater capacity of the mechanical peeling method was the reason for the low total cost per kilogram of Ambarella compared to the manual peeling method.

The variable cost accounted for 98% of machine cost, and the reason for this was the high cost of labour wages (90%). Meanwhile, less than 3% of the fixed cost was contributed to the total annual cost for the mechanical method due to the low cost of repair & maintenance, the interest of investment, depreciation, and shelter.

According to the comparative economic performance evaluation results, the newly designed peeler reported minimal break-even point values, and it is appropriate for SMSEs food processors that have annual Ambarella-based processed production of more than 378.05 kg/year, respectively.

4. Conclusion

The newly designed peeling machine has gained satisfactory performance in the evaluation process. The best horizontal drum angle for peeling Ambarella is $10°$. The peeling machine's performance does not vary between the two varieties of Ambarella. The peeling capacity of the new peeler in comparison to the manual peeling method for Ambarella is 21.85 times higher. The newly developed peeler achieves the minimum material loss (The maximum damaged percentage of mechanical peeling was less than 5% for both fruit types of Ambarella), which minimizes postharvest losses. The cost of operation and the labour requirement for the new peeler for Ambarella peeling were $1/21^{st}$ and $1/19^{th}$ lower than the conventional manual peeling.

Further, this peeler showed comparatively lower power consumption, repair & maintenance, and lubrication costs as 7%, 1% and 1% percentages of the annual cost, respectively. Since the break-even point of this machine was minimal (378.05 kg/year), it is appropriate for MSMEs.

Besides, the calculated cost for peeling one kilogram of Ambarella was LKR. 2.08. There were no ergonomic issues with the operator during the test runs. Thus, it can be concluded that the continuous type rotary drum abrasion peeling machine could be introduced as an appropriate solution for peeling Ambarella for MSMEs, and further improvements are needed to increase the efficiency of the peeling machine.

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