International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 5 Issue 4, May-June 2021 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Design, Development, and Performance Evaluation of a Mechanical Device for Harvesting Pineapple

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ABSTRACT

Pineapple (*Ananas comosus*) in family Bromeliaceaeis a large, succulent, and tasty fruit with immense health benefits. Among all the cultivation activities of pineapple, harvesting is the most difficult, time-consuming, and energy-intensive process due to the higher plant density and spiny leaves of pineapple plants. Although, mechanization helps to increase the efficiency and post-harvest quality, very little attention has been drawn to the mechanization of the harvesting process. Therefore, the aim of this study was to introduce an efficient mechanical method for harvesting to overcome the practical problems associated with manual harvesting. The major concept of this is to harvest more fruits from one place by minimizing movement in the cultivation. The long handle, fruit picker, stalk holder, cutter, and operating levers are the major components of this device. The remotely operated cutter and fruit gripper are fixed in one end of the 2m long handle and operating levers are attached to other end so that all the fruits within a nearly 2m radius circular area can be harvested from a one place. The performance of the mechanical harvester was evaluated compared to the manual method at a pineapple field in *Kurunegala* district of Sri Lanka. The Actual harvesting capacity of the device was 385 fruits $h^{-1}$with 84% efficiency while the manual method recorded it as 210 fruitsh^{-1} with 64% efficiency when it is operated by males in double row cultivation systems. Results clearly showed that the mechanical method saves more time considerably than the manual method.

***KEYWORDS:** Actual capacity, Fruit picker, Mechanical harvester, Pineapple*

How to cite this paper: P. D. Kahandage | S. W. Hettiarachchi | G. V. T. V. Weerasooriya | E. J. Kosgollegedara | S. D. S. Piyathissa "Design, Development, and Performance Evaluation of a Mechanical Device for Harvesting Pineapple" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-5 | Issue-4, June 2021, pp.1109-1116, URL: www.ijtsrd.com/papers/ijtsrd42548.pdf

IJTSRD42548

1. INTRODUCTION:

Pineapple *(Ananascomosus*), which is extensively grown in Costa Rica, Brazil, Philippines, Thailand, Indonesia, India, Nigeria, China, Mexico, and Columbia, is considered to be the king of fruits because of its attractive flavor (Pariona, 2018).Pineapple fruit has immense health benefits as it contains considerable amount of dietary fiber, calcium, potassium, manganese and vitamin C while the fat and cholesterol content are very low (Joy, 2010). Pineapple can be grown in most of the areas of Sri Lanka, but it is prominent in the low country wet zone and intermediate zones (Department of Agriculture, 2015). The total pineapple cultivated area of Sri Lanka is about 4783 ha and total production is near to 40339000 fruits in 2017 (Department of Agriculture, 2018). *Kurunegala* and *Gampaha* districts account for more than 83% of the total production of the country (Department of Agriculture, 2015). Although both single and double row cultivation systems are recommended for pineapple, the double row system is the most popular practicing system as it gives a higher plant density. In the single row system, space between the rows should be 150 cm, and space between two plants should be 60 cm so that it allows for a population of 11,000 plants ha^{-1}. In the double row system, two rows spaced 70-80 cm apart are arranged all over the land with a spacing of 150 cm. The suckers should be planted with 45 – 60 cm space within the rows. This system gives a plant density of 25,000 - 29,000 plants ha^{-1} (Ho-a-Shu,1999).Among the *Kew* and *Mauritius* the widely cultivated varieties in the world, in Sri Lanka *Mauritius* is the most popular variety which cultivates over 95% of cultivating extents, while *Kew* is only 5% (Department of Agriculture, 2015). The fruits of variety *Kew* are cylindrical in shape and sour in taste and fruit weight ranges from 2.5 kg to 4 kg. The fruit weight of Mauritius is 1.2-2 kg, and the average diameter of the fruit is 12 cm(Department of Agriculture, 2015).

In pineapple cultivation in Sri Lanka, except for land preparation, all other practices such as planting, weeding, irrigation, fertilizer application, hormone application, earthing up, and harvesting are done manually. According to the Department of Agriculture, Sri Lanka, labor scarcity is one of the major issues of the pineapple industry of Sri Lanka. Harvesting is done with a sharp knife with a long wooden handle called pineapple knife, severing the fruits talk with a clean-cut retaining 5-7 cm of the stalk with the fruit (Joy, 2016). This is not an efficient method due to some problems such as frequent movement of the operator from plant to plant, injuries caused by sharp and spiny leaves, damaging fruits and leaves, and high time consumption. The post-harvest loss of pineapple is estimated as 6.82% of harvested fruits due to several reasons at the farm level as pineapple fruits are very sensitive for the pressure, of which 1.85% is due to the harvesting damages (Ningombam*et al*., 2019). Proper mechanization of this difficult task will reduce the problems of labor shortage, safety problems during harvesting process, problems of post-harvest losses and high cost of production. Therefore, this study aimed to design and construct a suitable mechanical device to overcome all these practical problems associated with manual harvesting of pineapple.

2. Materials and methods

All the design and fabrication work were carried out at the Engineering workshop of Faculty of Agriculture, Rajarata University of Sri Lanka and performance of the newly introduced harvester was evaluated at some selected pineapple plantations in *Kurunegala* district of Sri Lanka.

2.1. Design considerations

Reducing the walking distance of the operator, low weight, less damage to fruits and plants, Safety of operator, harvesting efficiency, affordability, and ergonomic factors were considered when designing the pineapple harvester. Easy assembling, dissembling and maintenance at village level were also considered.

2.2. Components of the machine

The mechanical pineapple harvester consists of several components such as fruit picker, stalk holder, stalk cutter, handle, and operating levers (Figure. 01).

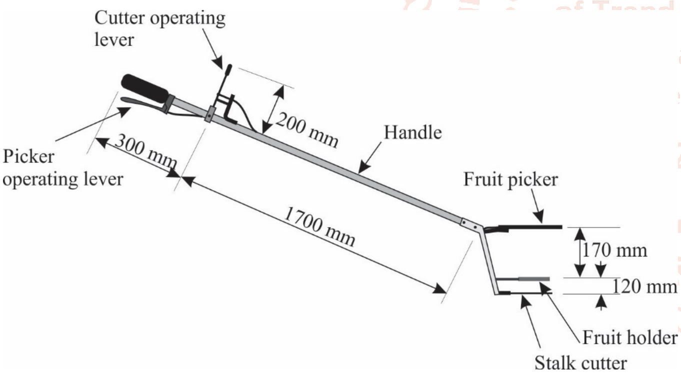
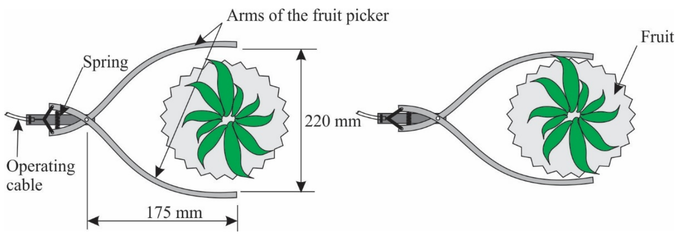


Figure 01: Components and dimensions of the pineapple harvester

The handle carries all the components together and determines the length of the harvester. A lightweight Galvanized Iron (GI) pipe with 25 mm diameter was used to fabricate the handle. The total length of the handle was 2000 mm. As the pineapple fruit should be hold tightly before making the cut the fruit picker was designed to hold the fruit firmly while cutting and taking away. It is attached to the handle just above the stalk cutter. To facilitate the picker to grasp any size of pineapple fruit, the average diameter of pineapple fruits of Sri Lanka was considered when deciding the maximum gap between arms of the picker. As the average diameter of *Mauritius* fruits is about 200 mmthe maximum gap between arms was decided as 220 mm. Operation of the arms of the pickershould be done by a lever attached to the operating end of the handle and power is transmitted using a flexible cable.

After cutting the stalk, the separated fruit should be taken out and placed in a bag or another place. When, the fruit is lifted by the handle, as the support from the fruit picker is not enough the fruit holder was designed in U shape and the gap between two pegs was determined as 30 mm. Fruit holder was fixed on the main handle 10 cm above the stalk cutter, because there should be at least 10 cm length of stalk remained for postharvest handling of fruit (Department of Agriculture, 2015).According to the Royal University of Bhutan 2006, the average fruit height is 30 cm. Therefore, the picker was fixed on the main frame as 17 cm above the fruit holder in order to increase the picker stability. The Figure. 02 shows the components and the dimensions of the fruit picker before operating and after operating.



(a) (b)

Figure 02: (a) Fruit picker before operating (b) Fruit picker after operating.

The stalk cutter was designed to separate the fruit from the plant by cutting the stalk. Stalk cutter is consisted with a movable blade (stainless steel, sharp and strong), blade mounted frame, flexible cable, and springs. It is connected to the handle at its lower end. The blade of the cutter was mounted, and spring loaded on a light frame and connected with an operating lever, which is at the operating end of the handle so that the cutter can be operated remotely. A spring has been used to return the blade to initial position after cutting process is accomplished. Movable length of the blade is set as 30 mm as the average diameter of pineapple stalk is 25 mm(Food and Agricultural Organization,2013). The Figure. 03 shows position of the blade before operating and after operating the cutter.

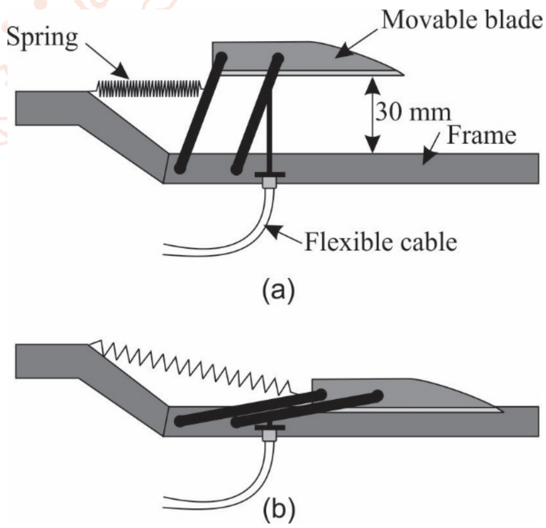


Figure 03: (a) Position of the blade before operating the cutter and (b) after operating the cutter.

Operating the fruit picker and stalk cutter can be done using two separate levers at the operating end of the handle by the means of flexible cables. As a comparatively higher force is required to operate the stalk cutter, a 200 mm length lever is fixed on to the handle from 300 mm apart from the fruit picker operating lever. Flexible cables connected with levers are extending to the other points through the inside of the handle.

2.3. Material selection

As the material can affect for the quality and cost of the machine, the selection of the most suitable material for a design is one of the difficult and important things of the whole process. The best material is one which serves the desired objective at the minimum cost. According to Khurmi and Gupta, 2006, availability of the materials, suitability of the materials for the working conditions, cost, durability, strength, corrosion resistance, lightness, flexibility, and workability were considered when selecting the material. Therefore, galvanized steel, mild steel, stainless steel, flexible cables, and rubber grips were used in fabrication. The table 01 gives the selected material and selection criteria for each component.

Table 01: Material and selection criteria for components

Component	Criteria for selection	Selected material
Handle	Lightness, Strength, Corrosion resistance,Cost	Galvanized Iron (GI) pipe
Fruit picker	Availability, workability, strength, cost	Mild steel
Fruit holder	Availability, workability, strength, cost	Mild steel
Fruit picker operating levers	Availability, strength, cost	Plastic
Stalk cutter operating lever	Availability, workability, strength, cost	Mild steel
Stalk cutter	Strength, Lightness, Corrosion, and acidic reaction resistance	Stainless steel
Stalk cutter frame	Strength, cost, wear resistance and availability	Mild steel
Grips	Flexibility, strength, wear resistance, availability	Rubber

2.4. Fastening methods

Ideally, a product design should reduce to a minimum number of parts requiring assembly(Timothy, 2004). However, the fastening and assembly of several components is a necessity in most situations. In this design, permanent, semi-permanent and removable fastening methods have been used and special attention has been drawn for removable fastening as this type permits the parts to be readily dismantled without damaging the fastener.

2.5. Performance evaluation of the Pineapple harvesting device

The machine performances are important to know how well the machine does the job to which it is designed for, and whether it is profitable or not. Field capacity and field efficiency are two factors which measure the machine or equipment performances (Roth, 1975).Performance of the mechanical pineapple harvesting device was evaluated compared to the manual harvesting (harvesting with pineapple knife) in some selected pineapple cultivations in *Kurunegala* district of Sri Lanka. Six male and six female laborers were involved in evaluation of both harvesting methods in single row and double row pineapple cultivation systems with five replicates. Average time taken to harvest and collect one fruit, number of fruits harvested in 1 hour, number of damage fruits, number of damage leaves and injuries happened to operators were recorded. The Three factor factorial experimental design with the factors of gender, types of harvesting and cultivation pattern was used for this study. Analysis of variance (ANOVA) was performed with 2 levels (male and female) of factor 1, 2 levels (machine and manual) of factor 2 and 2 levels (single row and double row) factor 3. Mean separation was done using Tukey's mean separation procedure. Twenty operators as 10 males and 10 females (including those who involved in evaluation) were directed to operate the machine in the field for sufficient time duration and feedback of all the operators was collected using a pre-tested questionnaire. Comments on the easiness, appearance, user friendliness and affordability were recorded and summarized.

Determination of average time taken to harvest one fruit

Each laborer involved in evaluation process was directed to harvest ten fruits continuously and collect them into a one place. Total expended time was recorded, and average time was calculated.

$$\textit{Average time taken to harvest and collect one fruit} = \frac{\textit{Total time expended for ten fruits}}{10}$$

Determination of theoretical and actual capacities

The capacity of a machine is the amount of production gains within a specific time. It could be expressed as actually and theoretically. Theoretical capacity measures the total time (t) taken to harvest a single fruit and it is expressed by number of fruits can be harvested within one hour. Actual capacity measures the actual number of pineapple fruits harvested within an hour. Further, the actual capacity measures the performance of a machine under actual field conditions. Time taken to move from one place to another, unloading, adjustments, resting and other time losses were considered(Roth,1975).

$$\text{Theoretical Harvesting Capacity (THC)} = \frac{3600\ \text{s h} - 1}{\text{Average time taken to harvest and collect one fruit (s)}}$$

$$\text{Actual Harvesting Capacity (AHC)} = \text{Actual number of fruits harvested and collected within onehour}$$

Determination of efficiency

Efficiency of a machine gives an idea about wasted time during the work. It is calculated as apercentage (Roth, 1975).

$$\text{Harvesting Efficiency (\%)} = \frac{\text{AHC x 100}}{\text{THC}}$$

Determination of fruit damages and leaves damages

Damaged fruit percentage and number of damaged leaves were calculated using recorded data.

$$\text{Damaged fruit (\%)} = \frac{\text{Number of damaged fruits x 100}}{\text{Number of total harvested fruits}}$$

$$\text{Damaged leaves} = \frac{\text{Number of damaged leaves}}{\text{Harvested area}}$$

3. Results and discussion

After several trails, a complete, simple, and successful prototype ofharvesting device was fabricated to harvest mature pineapple fruits conveniently. The total production cost of the harvesting device was LKR 12,500.00 including all the material and labor cost.

When operating the mechanical device, the operator has to hold the device by both hands and the fruit holder and the cutter should be used to grasp the stalk of the pineapple fruit. Thenthe fruit should be tightly kept by the fruit picker.At the same time, the cutter should be operated by the cutter operating lever to detach the stalk. The separated fruit should be lifted and placed on another place by releasing the gripper operating lever.

The fabricated harvesting device is shown by following Plate01 and some major components are shown by Plate 02,03 and 04.

Plate 01: Fabricated Pineapple harvesting device.

Plate 02: Stalk cutter of Pineapple harvesting device

Plate 03: Cutter operating lever of Pineapple harvesting device

Plate 04: Fruit picker operating lever of Pineapple harvesting device

3.1. Specifications of the mechanical harvester

Several specifications of the newly introduce Pineapple harvesting device are given by Table 01.

Table 02: Specifications of the Pineapple harvesting device

Parameter	Value
Length of the handle	2000mm
Total weight	2.6 kg
Gap between fruit picker and the stalk holder	170mm
Gap between fruit holder and stalk cutter	120mm
Maximum gap between picker arms	220mm
Gap between stalk holder's arms	30mm
Angle of the stalk cutter	35^0

3.2. Theoretical Harvesting Capacity (THC), Actual Harvesting Capacity (AHC) and Harvesting Efficiency (HE)

Theoretical harvesting capacity, actual harvesting capacity and harvesting efficiency of both harvesting methods for each operator were calculated separately for single row and double row cultivations. Following table 03, shows themean values for both male and female operators.

Table 03: Theoretical harvesting capacity, Actual harvesting capacity and Harvesting Efficiency of manual harvesting and mechanical harvesting

Gender	Parameter	Manual Harvesting		Mechanical Harvesting	
		Single row cultivation	Double row cultivation	Single row cultivation	Double row cultivation
Male	THC (Fruits h^{-1})	327	327	450	450
	AHC (Fruits h^{-1})	235	210	343	385
	E (%)	71.8	64.2	76.2	84.4
Female	THC (Fruits h^{-1})	300	300	400	400
	AHC (Fruits h^{-1})	195	162	295	331
	E (%)	65.0	54	73.7	82.7

Harvesting capacities

The results of the three-way ANOVA revealed that, the main effects of gender, type of harvesting and cropping pattern on actual harvesting capacity was significantly different ($p<0.05$). According to the results, the actual mean harvesting capacities of male labors in single raw cultivation systems were 343.17 ± 2.63 fruits $h^{-1}$with machine and 235.00 ± 1.78 fruits h^{-1} manual method while the actual harvesting capacities on double raw cultivations were 384.50 ±2.07 fruits h^{-1} with machine and 210.67±1.86 fruits h^{-1} with manual method. In addition to that, the actual mean harvesting capacities of female labors on single raw cultivation were 294.83±1.83 fruits h^{-1} with machine and 194.67±1.63 fruits h^{-1} manual method while the actual harvesting capacities on double raw cultivations were 330.83 ±.98 fruits h^{-1} with machine and 162.33±2.33 fruits h^{-1} with manual method. It has been proven that, the machine has shown significant performances compared to the manual harvesting. According to Jayasiri, *et al.,* 2014, the actual capacity of a manually operated pineapple harvester was recorded as 0.03 hah^{-1} and there was not any significant deferent between manual harvesting and the mechanical harvesting. Therefore, the harvesting capacity of the mechanical device of this study is satisfied. Figure 04. shows the main effects on actual harvesting capacity.

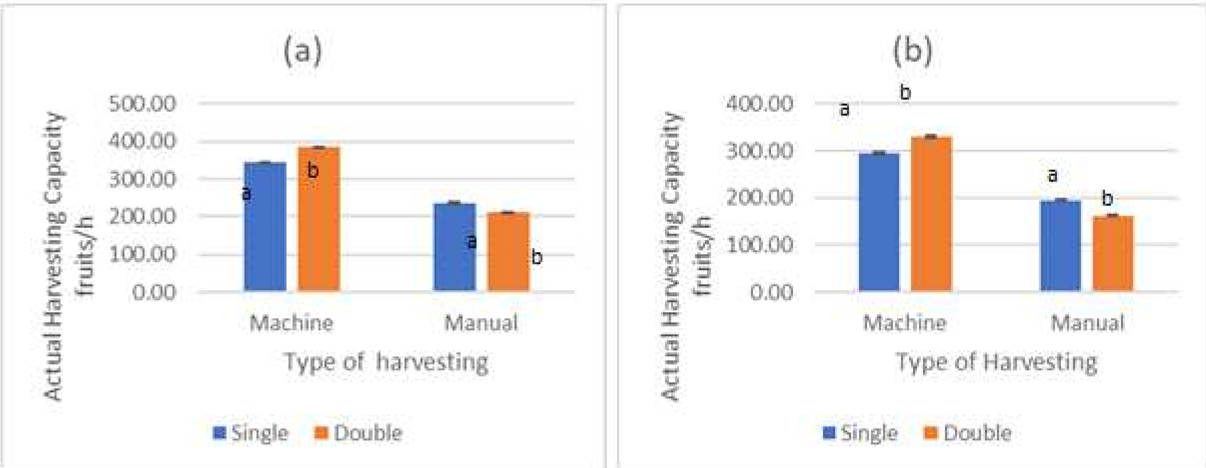


Figure 04: Main effects on actual harvesting capacity (a) male labours, (b) female labour. The columns with different letters are statistically significant

The harvesting capacity of male is higher than female in both single and double row cultivation systems and in both mechanical and manual methods. It seems that, comparatively higher physical strength of male has been affected for this. According to Mba, 2019, hired women often engage in pineapple harvesting worldwide. Therefore, it is very important to get involved the women in the performance evaluation of the mechanical harvester. A drastic drop of actual capacity was observed moving from machine to manual harvesting method in double raw in comparison to single raw cultivations. The reason was lesser moving and turning times for harvesting in double raw cultivations in comparison to the single raw cultivations since, the two plant rows were kept adjacent.Manual harvesting of pineapple in double row cultivation is difficult than single row cultivation as the high plant density disturb to move from place to place. Improper management of pineapple plantations is also a reason for this difficulty. But, in mechanical method both male and female have shown higher harvesting capacities in double row systems compare to the single row systems as the mechanical harvester facilitate to harvest number of fruits from a one place without moving.

Moreover, the interaction effects of gender & type of harvesting, gender & cropping pattern, and cropping pattern & type of harvesting were significantly different ($P<0.05$). The interaction plots were shown in the figure 2.

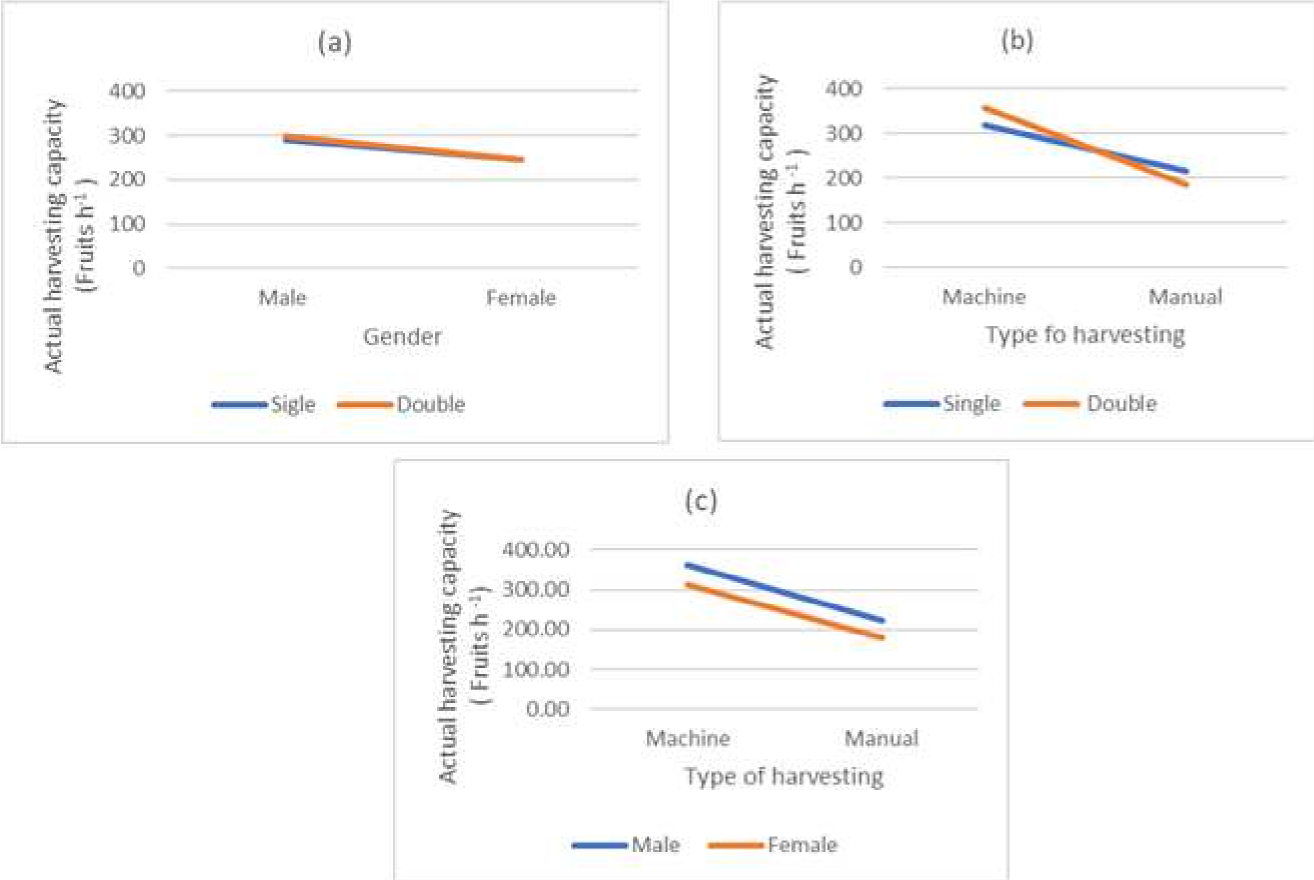


Figure 05: Interaction effects of (a) Gender and Cropping pattern, (b) Cropping pattern and type of harvesting, (c) Gender and Type of harvesting.

Harvesting efficiency

The results of the three-way ANOVA revealed that, the main effects of gender, type of harvesting and cropping pattern on harvesting efficiency was significantly different ($p<0.05$). Figure 3. shows the main effects on harvesting efficiencies.

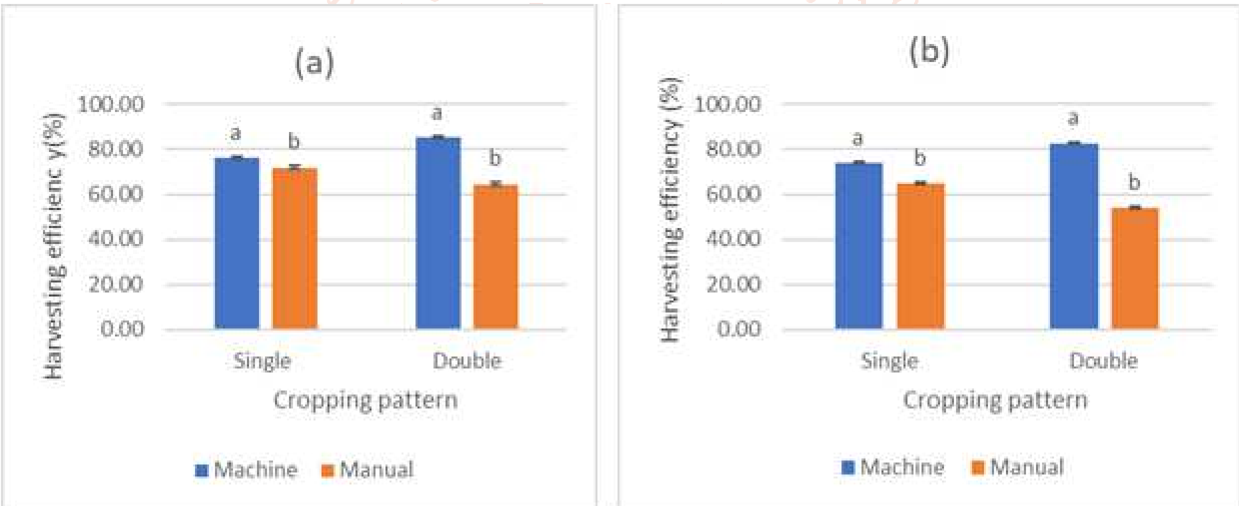


Figure 06: Main effects on harvesting efficiency (a) male labours, (b) female labour. The bars with different letters are statistically significant.

In double row cultivation, the machine has shown a comparatively higher efficiency since the machine facilitates to harvest many fruits at a one place in double row cultivation.

According to the table 03, average time taken to harvest and collect one fruit is comparatively lower in manual method so that theoretical capacities of manual method for both single and double row cultivations are higher than mechanical method. But actual capacities of both male and female are higher in mechanical method irrespective to the cultivation pattern. That is due to the ability of harvesting number of fruits (more than 25) at a one place reduce the walking distance and avoid the disturbances of the field. In manual method, operator has to move plant to plant overcoming the disturbances creating by high plant density and spiny leaves. It is very clear that, in double row cultivation, actual capacities of both male and female are lower than that of the single row cultivation as plant density of double row cultivation is very higher than single row cultivation.

Efficiency of mechanical harvesting is considerably higher than manual harvesting irrespective to the gender and cultivation pattern. As the theoretical capacities are higher and actual capacities are lower in manual method, efficiencies have been lowered. Higher efficiencies of mechanical method reflect that, time wastage of mechanical method is lower than manual method.

There is a significant difference ($p>0.05$) in actual capacities and efficiencies of manual harvesting and mechanical harvesting methods. As well as, there is a significant difference ($p>0.05$) between male and female in actual capacity and efficiency of mechanical method. It reflects that, male can easily operate the harvesting device than female.

3.3. Damaged fruits, leaves and injuries caused to operators.

All the damages happened to the fruits, leaves and operators were considered and recorded. Following table 04 shows the recorded data at the evaluation process.

Table 04: Damaged fruits, leaves and injuries caused to operators.

Parameter	Manual Method	Mechanical Device
Damaged fruits (%)	3	0
Damaged leaves (Leaves/ Acre)	425	106
Injuries caused to operators	0	0

Any crushed or cut leaf or fruit during the harvesting operation was considered as a damaged leaf or fruit. According to the data given by the table03, five fruits damages and several leaves damages have been recorded in manual method. But in mechanical methods, there was not any damage for fruits but several damages for leaves have been recorded. When the pineapple knife is been used for harvesting, some damages can be happened due to the sharpness and uncontrolled cutting. When the mechanical device is used, due to the size of the cutter and other components of the device, leaves can be damaged. But the leaves damage of the mechanical device is very lower than the manual method. As the operators involved for the evaluation process were asked to wear fully protective cloths including boots, gloves, trousers and long sleeves shirts, no injuries for operators were recorded.

3.4. User feedback on the machine

Summary of the user feedback is given in Table 5.

Table 05: Summery of user feedback

	Very good		Good		Satisfactory		Bad		Very bad	
	M	F	M	F	M	F	M	F	M	F
Convenience of operation	50%	20%	-	20%	-	10%	-		-	
Weight of the machine	50%	10%	-	20%	-	10%	-	10%	-	
Overall performance of the machine	40%	20%	10%	30%	-		-		-	
Appearance of the product	50%	30%	-	20%	-		-		-	
Overall product quality	40%	35%	10%	5%	-	10%	-		-	
Safety	50%	25%	-	25%	-	5%	-		-	
Dissembling of the machine	40%	-	10%	20%	-	30%	-		-	
Affordability of the machine	40%	35%	-	25%	-		-		-	

M- male operator, F- female operator

Involvement of users in development of a usable machine or a system is very important to reach the end-users' expectations (Karat, 1997; Sari, 2003). In compliance with the feedback summary, male operators are more satisfied with all the aspects considered in the questionnaire survey compared to the female operators. Although, most of the operators irrespective to the gender have responded positively on each aspect, attention should be paid to improve more to satisfy the users especially by reducing the weight and improving the convenience of operation.

4. Conclusions

In Sri Lanka, the manual harvesting is practiced due to the unavailability of any effective and affordable mechanical method for pineapple harvesting. Therefore, in the effort of introducing a new mechanical method for harvesting of pineapple, this new harvesting device has shown satisfactory results with both male and female labors with the capacities of 385 fruits $h^{-1}$and 331fruits h^{-1}respectively in double row cultivated fields under nearly 84% efficiency. Even in single row cultivated fields, the mechanical device has shown marvelous results compared to the manual method. As the capacities of the device for both male and female were higher than the manual method, it can be concluded that, a special skill to operate the device is not required. Since, there is a significant difference between male and female in actual capacity and efficiency, it can be concluded that, male can conveniently operate the device than female. Required forces to operate the levers and weight of the device should be reduced to make the operation convenient for female too. When the recommended protective cloths are used when harvesting, both methods are safe for operators. Damages for fruits and leaves can be minimized when the mechanical method is used and it can be concluded that, the post-harvest losses of pineapple can be reduced by newly introduced mechanical device. As the total production cost is very low (LKR 12,500.00), the mechanical harvesting device is affordable even for small scale farmers. The performance of the mechanical device can be further improved by introducing a lightweight motorized cutter.

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