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Tractor-operated hydraulically controlled tree shaker for harvesting fruits

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ABSTRACT

A tractor-operated hydraulically controlled tree shaker was developed to harvest Aonla (*Phyllanthus emblica*) and Jamun (*Syzygium cumini*) fruits. This machine generates vibration to shake fruit trees with provision to hold the tree trunk up to 2438 mm high. Besides, a collecting basket made of green net with fully opened diameter of 6706 mm has also been developed. Performance assessment of the machine was carried out on Aonla and Jamun fruit trees at two different stroke rates and compared with the traditional method of fruit harvesting. The best results were obtained at stroke rates 1480 ± 8 and 1600 ± 12 rpm for Aonla and Jamun trees, respectively. The average harvest per tree at these stroke rates was 52.99 kg and 12.53 kg for Aonla and Jamun trees, respectively. Mature, immature, and damaged harvested fruits were 78.59%, 5.59% and 15.81%, respectively, for Aonla. In Jamun, the mature, immature, and damaged harvests were 82.34%, 7.10%, and 10.56%, respectively. The overall fuel consumption for harvesting Aonla and Jamun fruits was 5.6 and 6.06 l/h, respectively. For Aonla, the cost of harvesting with the machine was Rs. 5.03/kg, whereas it was Rs. 20.94/kg for jamun. In contrast, the cost of harvesting in the traditional method was Rs. 4.20/kg for Aonla and Rs. 15/kg for Jamun. The cost of operation was higher due to the harvesting of untrained, non-pruned trees and the machine being a functional prototype. The overall saving in labour was 74-80% in Aonla and 75-80% in Jamun fruit harvesting compared to the manual method.

Key words: *Syzygium cumini L.,* Mechanical fruit harvester, Vibratory trunk shaker

INTRODUCTION

The fruit and vegetable industry is the largest and fastest-growing sector in global agricultural production (Wang *et al.,15*). India shares a significant amount of the world's total fruit production (870 million tonnes) by making an annual contribution of about 97.35 million tonnes (Anonymous, 2). Vegetable and fruit cultivation can serve as a potential solution to alleviate the issues created due to the wheat-paddy rotation in the fields of Punjab. In its diversification policy, the Punjab government has recommended increasing the area under fruits and vegetables (Anonymous, 1). The labour employed in fruit cultivation is predominantly dedicated to harvesting, which is the most labour-intensive (He *et al.,* 7) and time-consuming part of the production process. The conventional approach towards picking fruits entails climbing dangerous heights, and the labour involved is at high risk for accidents (Zhang; 18). Applying mechanical harvesting may be a cost-effective alternative to manual harvesting, ensuring the timeliness of product supply in a competitive market while circumventing the issues of the uncertainty of labour availability (Sanders, 11).

In past decades, four main types of vibratory systems have been developed and evaluated for their effectiveness in vibration fruit harvesting, which includes limb shakers, canopy shakers (Sumner; 13), trunk shakers (Whitney *et al.,* 16), which involve mechanical vibration of tree components through direct contact, and air shakers, which involve oscillation by air blast (Sarkar; 12). Globally, mechanical harvesting systems based on the vibratory motion have been extensively applied for the harvesting of various fruit crops, including oranges (Torregrosa *et al.,* 14), apples (Kleine and Karkee, 8), grapes (Caprara and Pezzi, 3), olives (Robb and Ravetti, 10), sweet cherries (Chen *et al.,* 4), coffee beans (Ferreira *et al.,* 6) and blueberries (Yu *et al.,* 17). However, the automatic harvesters developed in other countries are not necessarily adaptable to the Indian orchards since they are specifically designed to cater to entirely different geo-climactic conditions. In addition, tree or canopy attributes and orchard design necessitate careful consideration of the type of mechanical harvester suitable for the crop. Hence, a tractor-operated hydraulically controlled tree shaker has been developed to generate enough vibration to shake the tree along with the trunk holding at desired position up to 2438 mm.

MATERIALS AND METHODS

A tractor-operated tree shaker for mechanical harvesting of fruit crops was developed (Table 1). This machine was configured and divided into

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Table 1. Specifications of the developed tree shaker

Description of component	Specifications
Type of machine	Mounted with a three-point hitch
Power source, hp	PTO, 50
Weight, kg	940
Dimension (LXW), mm	4200 X 1450
Tank capacity, l	60
Length of arm, mm	2000
Weight of full disc (each), kg	7.2
Weight of half disc (each), kg	3.4
Thickness of disc, mm	16
Diameter of rotor shaft on which discs are mounted, mm	55
Vertical distance between disc, mm	70
Hydraulic cylinders	2 (extended arm), 2 (grippers)
Collecting basket, mm	6705.6
Operators required	2

three main components: the main frame, telescopic arm, and vibration unit. The heavy-duty main frame consisted of a three-point hitch system for mounting on the tractor, an oil sump for the hydraulic system, a hydraulic motor, a hydraulic cylinder, and other accessories. The telescopic arm was made of high-grade mild steel and mounted to the main frame for carrying the hose pipes and vibration unit. The upright movement to the telescopic arm was actuated by the hydraulic cylinder, powered by the main frame's hydraulic unit. Also, another hydraulic cylinder was provided on the telescopic arm to carry the movement of the vibration unit.

The vibration unit consisted of a hydraulic motor and shaft, along with two full discs and two half discs mounted on the full discs. The vibration in the vibrating unit was generated by the concentric discs mounted on the shaft. The concentric discs rotate on their axes to generate vibrations. The shaft was driven by a hydraulic motor fixed on top of the vibration unit. The motor was powered by the main frame hydraulic unit. The stroke rate of the tree shaking mechanism could be varied according to the vibration required on the fruit-bearing branches. The vibration unit also carries the grippers that grasp the tree trunk and transmits the generated vibrations to the tree. Cylinders powered by the hydraulic unit hydraulically controlled grippers. The central control unit of the developed tree shaker was located behind the operator's seat and controlled all movements and vibration speed. In addition, a collecting basket made of green net with an extended diameter of around 6706 mm (22 ft) was developed. Two persons controlled the basket's extension and retraction mechanism manually. The mechanism for the falling of fruits on the collecting basket ensured that the fruits moved effortlessly to the centre of the fixture, where an outlet was provided. A view of the developed tractor-operated tree shaker mounted on a tree along with a collecting basket is shown in Fig. 1.

The developed tractor-operated tree shaker with a collection unit was evaluated in the field conditions for the harvesting of fruit crops between the years 2021 to 2023. (Fig. 2). Two types of fruit trees, i.e. Aonla (*Phyllanthus emblica*) and Jamun (*Syzygium cumini L.*), were selected for harvesting with the developed machine. The experiments for harvesting Aonla and Jamun trees were carried out at Punjab Agricultural University, Ludhiana. One location at the Village, Birmi, Ludhiana, was also considered for the Jaumn tree. Based on preliminary laboratory studies, green net collecting baskets and rubber-type material grippers were selected for field evaluation.

Moreover, the selection of stroke rate was primarily based on the parameters such as the magnitude of vibration (displacement, acceleration) transferred to the tree, which is capable of harvesting fruits from branches, ease of operation and damage to the tree. Higher vibrations due to higher stroke rates may result in long-term damage to the overall tree structure, even if not visible immediately (Coppock 5; Li *et al.,* 9). Hence, two-stroke rates viz., SR1 (1354 $\pm$ 3 rpm for Aonla and 1500 $\pm$ 25 rpm for Jamun) and SR2 (1480 $\pm$ 8 rpm for Aonla and 1600 + 12 rpm for Jamun) have been selected and compared for evaluation of the developed machine. The field performance of the machine was assessed in terms of shaking time required per tree, fuel consumption, fruit detachment efficiency per tree, weight of harvested fruits, and percentage distribution of mature, immature, and damaged fruits.

Fig. 1. A view of the developed tractor-operated tree shaker mounted on the Jamun tree along with the collection unit

Fig. 2. A view of developed tractor-operated tree shaker harvesting Aonla fruit

All parameters were further compared with the control treatment, which represented the traditional method of fruit harvesting.

In the case of Aonla, fruit detachment efficiency/ tree was calculated by counting the number of fruits on a branch before operating the tree shaker, followed by counting the number of fruits remaining after the operation, followed by percentage calculation. Five branches were considered replications for counting fruits from each tree simultaneously during an experiment. The weight of harvested fruits was calculated using a weighing machine. Mature, immature, and damaged Aonla and Jamun fruits were manually segregated in the laboratory, and the percentage of mature, immature, and damaged fruits out of the total fruit harvested was subsequently calculated. Moreover, shaking time/tree (in min) at a particular stroke rate was recorded using a stopwatch, measuring the actual duration of the fruits falling from the tree during a harvesting operation. The fuel consumption of the tractor was measured with the help of a fuel flow meter having a least count of 1 ml, which was placed in the middle of the fuel line. The fuel meter reading was recorded before and after the operation. It was expressed as litres per hour. The formula used for fuel consumption is given below:

$$\text{Fuel consumption, l/h} = \frac{\text{Fuel consumed (ml)}}{\text{Time (s)}} \times 3.6$$

Comparative field evaluation of the developed tree shaker with collection unit and the traditional (control) treatment were statistically analyzed using online statistical software SAS ON DEMAND. Statistical analysis was carried out at a 5% significance level for analysis of variance, and Tukey's HSD post hoc test was applied to compare different treatment combinations. The traditional method of fruit harvesting adopted during the study involved climbing ladders for subsequent manual harvesting of fruits. The labour carried the harvesting bags on their shoulders and was tethered around their waist. Each fruit was hand-picked after identification and assessment of the maturity of the fruits. The straight-line method was used to calculate the economics of the tree shaker including the components such as fixed cost and the variable cost of individual steps. The cost of operation was determined as per BIS code IS 9164.

RESULTS AND DISCUSSION

The mean values of different parameters viz., shaking time, fruit detachment efficiency, weight of harvested fruits, fuel consumption, mature, immature and damage of fruits corresponding to stroke rates (1 and 2) and control for harvesting of Aonla fruits are given in Table 2.

It is depicted from the table that in case of shaking time per tree, the difference between stroke rate SR1 (21.6 s) and SR2 (24.4 s) was non-significant, whereas they are significantly lower as compared to the control treatment. It has been found that the weight of harvested fruits was significantly different for control treatment, stroke rate SR2, and SR1 of the

Table 2. Evaluation of developed tree shaker with collection unit in Aonla Orchards.

Parameters	SR1	SR2	Control	F-value	p-value
Shaking time/tree (min)	0.36^b	0.40^b	600^a	5752.56	<.0001
Fruit detachment efficiency (% age)	61.57^b	67.75^a (10.03)	-	6.14	0.0383
Weight of harvested fruits (kg)	47.50^c	52.98^b (11.53)	79^a	182.35	<.0001
Fuel consumption (l/h)	5.18^b	5.62^a (8.49)	-	6.50	0.0342
Mature (%)	75.91^b	78.59^b (3.53)	95.20^a	114.40	<.0001
Immature (%)	6.98^a	5.59^a (19.91)	0.38^b	23.06	<.0001
Damage (%)	17.09^a	15.81^a (7.48)	4.42^b	93.88	<.0001

*Same super scripted alphabets represent non-significant difference and figure in parenthesis shows a percentage increase or decrease from SR developed machine. Although the control treatment harvested 79 kg of fruit, which is significantly higher, 600 minutes were consumed during this harvest, whereas the SR1 and SR2 treatments were able to harvest 47.50 and 52.98 kg in 21.6s and 24.4s, respectively. The overall weight of harvested fruit for SR2 was 11.53% more than SR2. Fruit detachment efficiency/tree was significantly higher in the case of SR2 (67.75%) compared to SR1 (61.57%). The fruit detachment efficiency of SR2 was 10% more than SR3. Fruit detachment efficiency was not recorded for control treatment as in control treatment, more than one picking of fruits from a tree is carried out for ripened fruits. The developed machine, SR1 (5.18 l/h), displayed lower fuel consumption than SR2 (5.62 l/h). Although, the fuel consumption recorded for SR2 was 8.49 % more than for SR1.

Furthermore, the interaction between the control treatment and the developed machine for the percentage of mature, immature, and damaged fruits shows significant differences. This may be due to the reason that in the control treatment, the person first assesses the maturity of fruits before plucking, which results in a substantially higher percentage of mature fruits and a minimum percentage of immature and damaged fruits. Again, it has been observed that the damage in control treatment mainly occurs during the handling of fruits when packaged in fruit bags and while the labourer is descending from the ladder. It has also been observed that there was no significant difference in mature (75.91% and 78.59%), immature (6.98% and 5.59%) and damaged (17.09% and 15.81%) fruits percentages between SR1 and SR2, respectively. However, the mature fruit percentage is higher for SR2 than SR1. Hence, it can be concluded that both stroke rates significantly differ for fruit detachment efficiency, weight of harvested fruits, and fuel consumption. However, both stroke rates do not show any significant difference in the requirement of shaking time/tree and percentage of mature, immature, and damaged fruits, while being significantly different from the control treatment in terms of these parameters.

Trends similar to the Aonla tree have been observed in the case of Jamun trees for evaluation of developed tree shaker. The mean values of different parameters viz., shaking time, weight of harvested fruits, fuel consumption, percentage of mature, immature and damage of fruits corresponding to stroke rates (1 and 2) and control for Jamun fruits are presented in Table 3.

It was observed from the data presented in Table 3 that shaking time per tree was significantly lower for SR1 and SR2 when compared with the control treatment. However, stroke rate SR1 (21.6 s) and SR2 (21 s) was non-significant different from each other. It has been found that mean values for the weight of harvested fruits were significantly higher for SR2 (12.53 kg) followed by SR1 (10.29 kg) and control treatment (6.36 kg), respectively. Here, it has also been highlighted that control treatment took 160 min for this harvest. For fuel consumption recorded during harvesting with the developed machine, it has been found that SR1 (5.38 l/h) has a non-significant difference in the mean values from SR2 (6.06 l/h). In addition, the results between the control treatment and the developed machine show a significant difference in the percentage of mature, immature, and damaged fruits. Similar to Aonla trees, Jamun trees also showed that there was no significant difference in mature (84.59% and 82.33%), immature (4.70% and 7.10%) and damage (10.69% and 10.56%) fruits percentage between SR1 and SR2 respectively. Hence, it can be concluded that the stroke rate significantly differs for the weight of harvested fruits. Moreover, the stroke rate compared to the control treatment shows a significant difference to shaking time/tree, weight of harvested fruit and percentage of mature, immature and damaged fruits. However, the stroke rate does not show any significant difference between them in the requirement of shaking time/tree, fuel consumption and percentage of mature, immature and damaged fruits.

Table 3. Evaluation of developed tree shaker with collection unit for Jamun trees.

Parameters	SR1	SR2	Control	F-value	p-value
Shaking time/tree (min)	0.36^b	0.35^b	160^a	2038.75	<.0001
Weight of harvested fruits (kg)	10.29^b	12.53^a (21.7)	6.36^c	49.08	<.0001
Fuel consumption (l/h)	5.38^a	6.06^a (12.63)	-	4.72	0.0616
Mature (%)	84.59^b	82.33^b (2.67%)	97.00^a	36.89	<.0001
Immature (%)	4.70^a	7.10^a (51.06)	0.26^b	17.83	0.0003
Damage (%)	10.69^a	10.56^a (1.21)	2.74^b	36.08	<.0001

*Same super scripted alphabets represent non-significant difference and figure in parenthesis shows percentage increase or decrease from SR1

Table 4. Economics of developed tree shaker prototype (Aonla & Jamun).

Trees	Method of harvesting	Time taken (h)	Total Cost (Fixed + variable)	Total cost (Rs/kg)	Cost Saving (Rs/kg)	Labour saving (%)
Aonla (harvesting of 250 kg fruits)	Developed tree shaker	1	1256.65 (381.97 + 874.68)	5.03	- 0.83	74.25 - 80.5
	Manual	24	1050	4.20	-	-
Jamun (harvesting of 60 kg fruits)	Developed tree shaker	1	1256.65 (381.97 + 874.68)	20.94	-5.94	75 - 81.25
	Manual	20	900	15	-	-

Furthermore, the economics of the developed machine was carried out by considering fixed and variable cost components (Table 4). The tractor cost was assumed to be Rs. 6,50,000, and the machine cost was approximately Rs. 3,50,000. The average annual usage of the machine was 250 h. The total fixed cost was calculated to be Rs. 381.97/h. The total variable cost was Rs. 874.68 for harvesting 250 kg Aonla fruits, which was the same while harvesting 60 kg Jamun fruits.

The overall cost of harvesting one kg of Aonla fruits is Rs. 5.03/- with the developed machine, which is slightly higher but at par with the manual method of harvesting (Rs. 4.20/kg) (Table 4). Similarly, the overall cost of harvesting one kg of Jamun fruits is Rs. 20.94/- with the developed machine, which is higher than the manual method of harvesting (Rs. 15/kg). Hence, it can be concluded that the cost of operation with tractor operated tree shaker is costlier by Rs. 0.83/kg and Rs. 5.94/kg than the manual method of harvesting for Aonla and Jamun crops, respectively. This might be due to the reason that presently the orchards and trees are not trained and pruned for mechanical harvesting of fruits which results in an overall increase in cost and this machine being a first prototype. However, the labour saving with developed harvester is high and varies between 74.25 to 80.5% (Aonla) and 75 - 81.25% (Jamun). The developed tree shaker is best suited for fruit processing industries where mass harvesting is required.

AUTHORS' CONTRIBUTION

Conceptualization of research (AP, AKD, MS); Designing of the experiments (AP, AKD, GSM, RK); Contribution of experimental materials (AKD, RK, MS, GSM); Execution of field/lab experiments and data collection (AP, AKD, RK, GSM); Analysis of data and interpretation (AP, AKD, AKM); Preparation of the manuscript (AP, RK, AKM).

DECLARATION

The authors declare that they do not have any conflict of interest.

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