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Comparative Evaluation of Manual and Mechanical Jamun Fruit Harvesting

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ABSTRACT

Background: An engine operated jamun harvester to shake the limb with adjustable shaking frequency and amplitude was developed. The aim of the present study was to evaluate the performance of the jamun harvester and determine the suitable shaking frequency and amplitude to obtain maximum harvesting efficiency.

Methods: A 4×3 factorial experiment with completely randomized design was conducted to investigate the effects of shaking amplitude (10, 20, 30 and 40 mm) and frequency (2, 4 and 6 Hz) on percentage matured jamun harvested, fruit removal percentage and harvesting efficiency.

Result: Analysis of variance and mean comparison showed that the shaking amplitude and shaking frequency both had significant effect on percentage matured jamun harvested, fruit removal percentage and harvesting efficiency. The fruit removal percentage increased at higher levels of shaking amplitude and frequency. Complete fruit removal (100%) was achieved at 6 Hz shaking frequency and 40 mm amplitude, however shattering of leaves and immature fruits were observed. Therefore, shaking amplitude of 30 mm and shaking frequency of 6 Hz was recommended for Jamun harvesting with 93.15% fruit removal and 64.33% harvesting efficiency. The fruit detachment force to fruit weight ratio (FDF/W) of Jamun varied from 1.46 to 0.23. The cost of harvesting of jamun by the developed harvester was found to be approx. Rs. 9/- as compared to Rs. 15/- per kg fruit for manual harvesting.

Key words: Fruit detachment force, Fruit harvester, Harvesting efficiency, Jamun, Limb shaking amplitude and frequency, Percentage fruit removal.

INTRODUCTION

Jamun or Indian blackberry (*Syzygium cumini* L.) belongs to the family Myrtaceae, an underutilized potentially important indigenous minor fruit crop in India and south-east Asian countries, producing around 13.5 million tonnes in whole world, out of which 15.4% was supplied by India (Bukya and Madane, 2018). Since ancient times, the jamun fruit has been produced in India and the largest producer is Maharashtra, followed by others like Uttar Pradesh, Tamil Nadu, Gujarat and Assam (Ranjan *et al*., 2011). Jamun has a great economic importance due to its high potential as an alternative medicine to treat various diseases. A jamun tree produces on an average of 80 to 100 kg of fruit every year (Suklabaidya, 2018).

Different techniques used for harvesting of fruits such as shaking the tree trunk or the branch for litchi, apricot (Zohu *et al*., 2014; Du *et al*., 2012; Polat, *et al.,* 2007; Blanco-Roldan *et al*., 2009; Erdoğan *et al*., 2003), striking the limb for collection of sweet berries (Peterson *et al.,* 2003; Peterson, 2005) and picking a bunch of selected small fruits at once with hand held shaking combs or spinning combs powered by electric, pneumatic or gas (Nasinni and Proietti, 2014; Deboli *et al*., 2014; Gambella *et al*., 2013; Ferguson, 2006). The percentage of fruit removal of any tree may be influenced by shaking position, tree size and their structure (Wang *et al*., 2017). Researchers have found that the shaking frequency and amplitude, fruit detachment force (FDF) and shaking time are crucial factors for shaker harvesting. Although these harvesters are quite effective in small fruit harvesting, weight of the machine and vibration of the device can harm or exhaust the user with fatigue.

Moreover, mechanical harvesting by shaking the tree limb or branches with vibration stimulation should be performed to remove jamun fruits from the branch without any direct impact on the fruits. Harvesting machine are developed by Wang *et al.* (2014) to split the bunches of

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litchis with two multi-finger combs to impart vibration stimulation on the branch close to the fruits. Safdari *et al.* (2010) developed a portable type limb shaker for almond tree and tested for different shaking frequency (10, 13 and 15 Hz) and shaking time (5 and 10 s) at constant amplitude of 50 mm. They found that shaking frequency and time had a substantial impact on fruit detachment and shaking at a frequency of 15 Hz resulted in the maximum fruit detachment of 98%. Polat *et al.* (2007) studied mechanical harvesting of almond using an inertia-type limb shaker at frequencies of 10, 15 and 20 Hz and amplitudes of 40 and 50 mm for 10 s shaking duration. The shaking amplitude of 50 mm at frequency of 20 Hz was reported to be the best combination for maximum fruit removal with low vibration and reactive force.

Both time of harvesting and maturity stage of the fruit are the crucial factor for harvesting of horticultural crops as poor harvesting techniques lead to significant losses. The mechanization level in harvesting of jamun is very low, which necessitates the farmer climbing up the tree and occurs the risk of accidents (Pathak *et al.*, 2015). Though different approaches have been used for harvesting jamun by striking the fruits off the branches with a long stick or stripping the fruits and leaves together, there was significant waste of human labour, time, money and fruit quality. Thus, there was a need to develop a harvesting machine for jamun which is simple, affordable and convenient for the user. The main objective of this study is to develop and test the jamun harvester at different frequency and amplitude to recommend suitable operating conditions.

MATERIALS AND METHODS

Determination of fruit detachment force of *jamun*

Jamun fruits (variety IIHR-B-J-1) were collected at different maturity stages from five selected jamun trees located at Central Horticultural Experiment Station (CHES), Aiginia, Bhubaneswar, a Regional Station of ICAR- Indian Institute of Horticulture Research, Bangalore with latitude and longitude 20.2446°N and 85.7812°E, respectively in the year of 2022. The fruits were sorted on the basis of their colour into four groups with different maturity stages *i.e.*, green, pre-mature, mature and post-mature. The fruits along with the stem were plucked from the tree to study the fruit detachment force. Fruit detachment force for four different maturity stages of jamun was measured with the help of TA-XT plus Texture Analyzer (Stable Micro System, UK) with a load cell of 50 kg by tensile grip with stem being fixed to one end and the fruit to the other end. The fruit weight was determined by a digital balance. The fruit detachment force to weight ratio is an important property for harvesting of any fruit.

Development of Jamun harvester

The jamun harvester was developed to shake the limb for detaching the fruit (Fig 1). It is powered by a 1.5 hp single-cylinder spark ignition engine having speed of 8000 rpm. A M.S. flat was used as a long boom with connecting hole at one end and C-clamp bend at the other end. A centrifugal clutch was used to transmit power from the engine to the gear box. A worm gear was used for reduction of rotational speed between 100 to 480 rpm and changing the direction

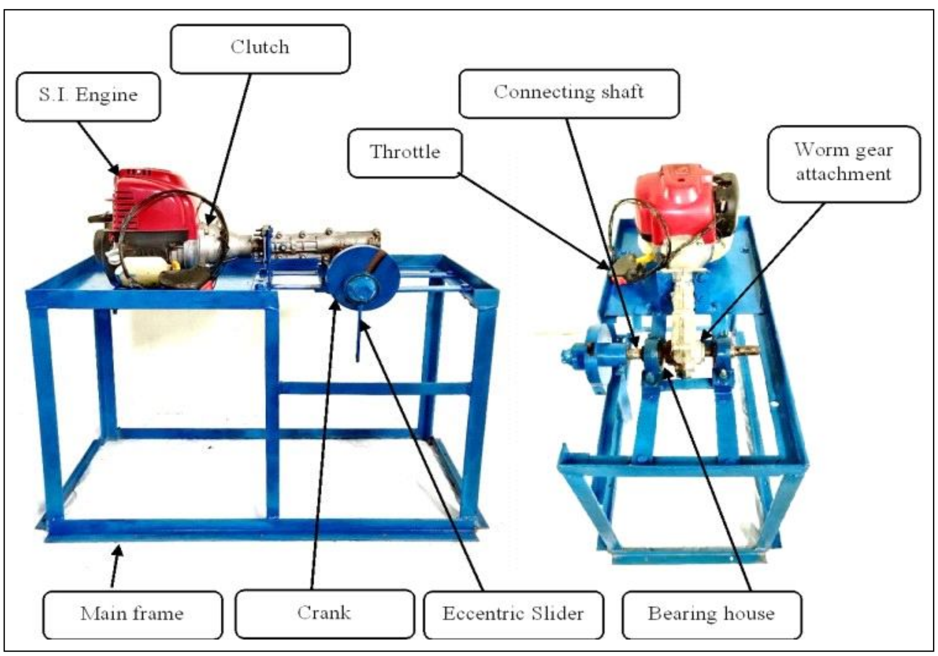

Fig 1: Isometric view of developed Jamun harvester.

of rotation. The maximum shaking frequency is 8 Hz at full engine throttle and three levels of shaking frequency were obtained with proper throttle setting of the engine. Slider-crank mechanism was used for generating reciprocating motion to the shaker. The position of the eccentric pin can be changed by sliding inside a groove in the crank to provide varying amplitude of vibration. Different shaking amplitudes were achieved by fixing the eccentric pin at amplitude distance off the centre of rotation of the crank. One end of the slider was connected to the eccentric pin while the other end to the boom link. The length of the boom can be increased depending on the height of the limb by connecting more booms with links. The C-clamp bend of the boom is connected to the limb for transmitting vibration for harvesting of the fruit. The engine was fixed on a M.S. angle frame. The detailed specification of the harvester is given in Table 1.

Testing of Jamun harvester

The experiments were carried out for harvesting Jamun at orchard of Central Horticultural Experiment Station (CHES), Aiginia, Bhubaneswar during the harvesting season in the first week of July, 2022 when jamun was 85 to 90% ripened.

A 4×3 factorial experiment with complete randomized design in three replications was conducted to evaluate the performance of the jamun harvester. The experiments were conducted at four shaking amplitudes of 10, 20, 30 and 40 mm and three shaking frequencies of 2, 4 and 6 Hz. Shaking amplitudes were achieved by fixing the eccentric pin at 10, 20, 30 and 40 mm off the centre of rotation of the crank and frequencies by setting the throttle of the engine. The harvester was placed under the limb of the jamun tree. The clamp of the main boom was attached to the limb of the tree to be harvested at a distance of 0.5 to 1 m from the trunk of the tree. The other end of the boom was connected to the slider by required boom connectors depending on the height of the limb. A jamun collection cloth was spread below the limb by fixing it to four rods inserted in the ground. The limb was shaken with required shaking amplitude and frequency for 5 s. The load on the limb was determined by a digital strain gauge by attaching its one end with the machine side link and the other end with the limb side boom while doing the experiment. The reading displayed on the device was noted down for different amplitude and frequency combination while harvesting. The harvested jamun fall on the cloth were collected and counted. Jamun was also harvested by conventional manual method by shaking the limb with a bamboo stick for comparison. The harvested lot was sorted for immature, mature and ripe jamun and counted. After mechanical harvesting, the remaining matured jamun in the limb was harvested manually and counted. The percentage matured jamun harvested, fruit removal percentage and harvesting efficiency were determined using following formula:

Percentage matured jamun harvested was determined by the following formula:

Matured jamun harvested (%) =

$$\frac{\text{No. of matured jamun}}{\text{Total no. of sample harvested}} \times 100$$

Fruit removal percentage was determined by the following formula (Wang *et al.,* 2017).

$$\text{Fruit removal (\%)} = \frac{\text{No. of fruits detached}}{\text{No. of detached fruits + No. of fruit remaing on the tree}} \times 100$$

Harvesting efficiency was calculated by the following formula:

Harvesting efficiency (%) =

$$\frac{\text{Matured jamun harvested (\%)} \times \text{Fruit remuval (\%)}}{100}$$

Comparison of cost of manual and mechanical harvesting

The cost of harvesting of jamun by manual and mechanical method were calculated and compared. The calculations were made based on the following assumptions.

- Depreciation @ 10% of machine cost.
- Interest @ 12% per annum.
- Repair and maintenance: @ 5% of machine cost.
- Machine operated for 4 hours a day.
- Labour charge: For manual harvesting @300/per day unskilled labour.
- For mechanical harvesting @ 400/- per day semiskilled labour.
- Fuel consumption @ 0.5 litre per day.

RESULTS AND DISCUSSION

Effect of maturity stages on fruit detachment force

The fruit detachment force (FDF) is an important parameter for harvesting of fruit which varies with maturity stage. The fruit detachment forces were found to be 6.76, 5.43, 4.48 and 2.70 N for green, pre-mature, mature and post-mature stage of jamun, respectively (Table 2). The FDF decreased and weight of the fruit increased with advancement of fruit maturity. The ratio of FDF to weight of fruit decreased with maturity and ranged from 1.46 to 0.23. The change in FDF/W ratio as a function of maturity stage were shown in Fig 2. It was observed that the ratio was higher for the green stage (1.46 N/g) and lowest for the post-mature stage (0.23 N/g). Similar findings were reported by Pathak *et al.* (2015) in pedal operated jamun tree shaker and Safdari *et al.* (2010) in portable limb shaker for almond tree.

Table 1: Specification details of Jamun harvester.

Details	Specification
Power source	1.5 hp S.I Engine
Overall dimension (L×W×H), mm	780×400×700
Weight, kg	29
Capacity, kg/h	20

Since ratio of FDF to weight varied in a close range among different maturity stages, there was shattering of green and pre-mature fruits during harvesting. So precise control of shaking amplitude and frequency is required for harvesting of jamun.

Effect of shaking amplitude and frequency on percentage matured jamun harvested, fruit removal percentage and harvesting efficiency

The effect of shaking amplitude and frequency on percentage matured jamun harvested, fruit removal percentage and harvesting efficiency are shown in Fig 3 to Fig 5. Analysis of variance for the effects of different levels of shaking amplitude and shaking frequency is shown in Table 3. The results indicated that the effects of shaking amplitude and frequency on percentage matured jamun harvested, fruit removal percentage and harvesting efficiency were highly significant (P<0.01). Similar results were reported by Polat *et al.* (2007); Safdari *et al.* (2010), Loghavi *et al.* (2011) and Wang *et al.* (2017).

The fruit removal percentage increased significantly with shaking amplitude and frequency. The maximum fruit

Table 2: Fruit detachment force (FDF) to weight ratio of jamun at different maturity stages.

Maturity stages	FDF (N)	Weight of fruit (g)	FDF/W
Green	6.76±0.72	4.67±0.84	1.46±0.15
Pre-mature	5.43±0.23	6.36±1.33	0.87±0.10
Mature	4.48±0.58	10.12±1.42	0.44±0.07
Post-mature	2.70±0.58	11.55±2.15	0.23±0.05

Table 3: Harvesting efficiency of jamun harvester at different shaking amplitude and frequency.

Sl. no.	Amplitude (mm)	Frequency (Hz)	Load (N)	% Matured jamun harvested	Fruit removal (%)	Harvesting efficiency (%)
Control	-	-	-	82.85±5.23	66.66±6.14	55.22±2.18
1	10	2	22.95±4.41^{f}	57.50±6.61^{d}	3.58±1.62^{i}	2.12±1.14^{i}
2	10	4	62.19±10.20^{e}	72.20±3.88^{a}	16.88±2.45^{gh}	12.21±2.09^{g}
3	10	6	82.30±12.94^{de}	68.60±1.68^{ac}	24.44±2.34^{f}	16.78±1.93^{f}
4	20	2	67.98±14.42^{e}	55.20±3.04^{d}	16.53±2.54^{h}	9.17±1.89^{h}
5	20	4	90.35±20.11^{de}	68.66±0.89^{abc}	49.63±2.67^{d}	34.07±1.65^{d}
6	20	6	100.25±14.22^{d}	69.93±1.21^{ab}	63.25±5.52^{c}	44.19±3.10^{c}
7	30	2	100.35±20.40^{d}	56.07±2.75^{d}	22.64±3.70^{gf}	12.75±2.59^{fg}
8	30	4	150.58±20.79^{c}	66.85±1.28^{b}	61.82±5.57^{c}	41.37±4.42^{c}
9	30	6	190.01±18.54^{b}	69.06±0.23^{ab}	93.15±5.00^{b}	64.33±3.54^{a}
10	40	2	190.21±17.46^{b}	59.68±0.84^{d}	39.92±1.74^{e}	23.82±0.87^{e}
11	40	4	196.29±17.95^{b}	64.19±0.92^{bc}	92.03±3.99^{b}	59.06±1.93^{b}
12	40	6	268.00±20.01^{a}	55.28±1.05^{d}	100^{a}	55.28±1.05^{b}

Values represents mean±standard deviation; The same letters in a column indicate no significant difference at P<0.05.

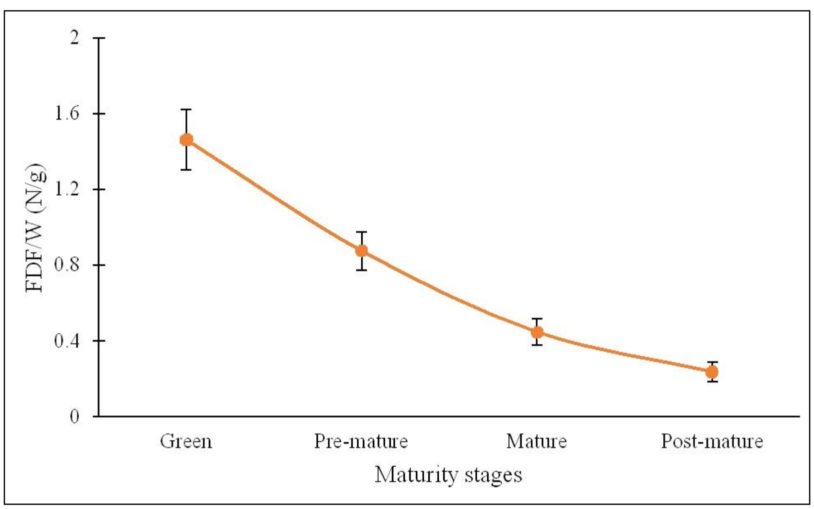

Fig 2: Variation of FDF/W at different maturity stages.

removal was obtained at 40 mm amplitude and 6 Hz frequency (100%) followed by 30 mm 6 Hz (93.15%) and 40 mm 4 Hz (92.03%) shaking. The fruit removal was 39.9% at highest shaking amplitude of 40 mm and lowest frequency of 2 Hz, whereas it was 24.4% at lowest shaking amplitude of 10 mm and highest frequency of 6 Hz. So, the shaking amplitude of 30-40 mm and frequency of 6 Hz is required for higher fruit removal. The harvesting efficiency was found to be 55.2% in manual harvesting. However, manual method was tedious giving more stress to the arms of the worker and the mechanical method was more comfortable as compared to manual method.

Similarly, the harvesting efficiency increased significantly with shaking amplitude and frequency. Highest harvesting efficiency of 64.3% was obtained at 30 mm amplitude and 6 Hz frequency followed by 40 mm 4 Hz and 40 mm 6 Hz shaking (Fig 4). Though fruit removal was highest at 40 mm amplitude and 6 Hz frequency, the harvesting efficiency was significantly higher at 30 mm amplitude and 6 Hz frequency due to shattering of more mature fruit. At higher amplitude of 40 mm and frequency of 6 Hz, small branches with leaves and immature fruit shattering were observed. So, the shaking amplitude of 30 mm and frequency of 6 Hz was found to be optimum for harvesting of jamun with maximum harvesting efficiency.

The load on the harvester increased significantly ($P<0.05$) with increase in shaking amplitude and frequency. The minimum load (22.95 N) was observed at 10 mm amplitude and 2 Hz frequency, whereas the maximum load (268.00 N) was recorded at 40 mm amplitude and 6 Hz frequency. Fig 6 indicates that the effect of amplitude on load is higher as compared to frequency of shaking. There was 225% increase in load from 10 to 40 mm increase in amplitude at 6 Hz, whereas 41% increase in load was observed with increase in frequency from 2 to 6 Hz at 40 mm amplitude. There was no significant difference in load on the harvester operated at 30 mm amplitude with 6 Hz and 40 mm amplitude with 2 Hz and 4 Hz frequency.

Therefore, shaking amplitude of 30 mm with 6 Hz frequency was preferred for operation of the harvester taking less load and higher harvesting efficiency into consideration as compared to 40 mm amplitude with 6 Hz frequency.

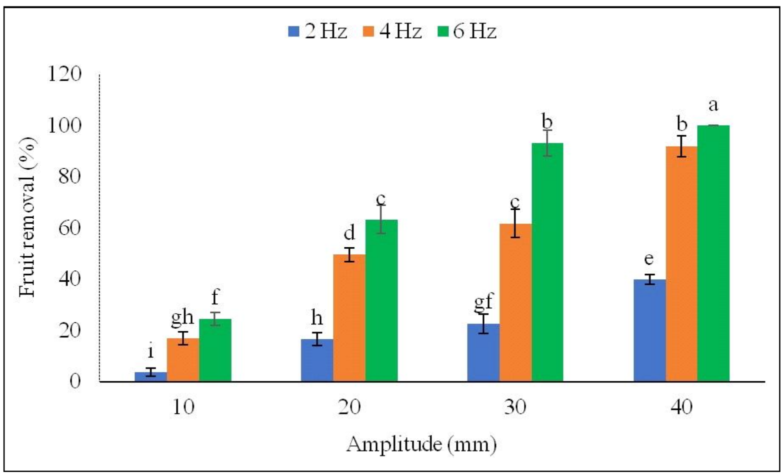

Fig 3: Effect of shaking amplitude and frequency on fruit removal percentage.

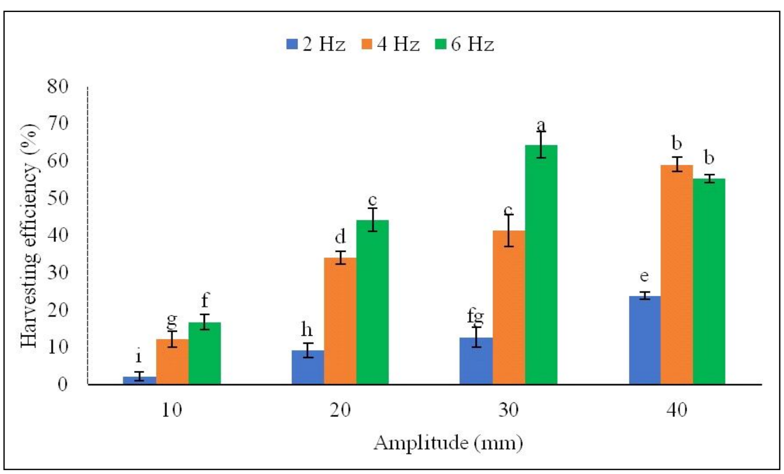

Fig 4: Effect of shaking amplitude and frequency on harvesting efficiency.

Table 4: Comparison of cost of harvesting of jamun by manual and mechanical method.

Parameters	Manual harvesting	Mechanical harvesting
Cost of machine	-	30,000/-
Fixed cost		
Depreciation	-	3,000/-
Interest	-	3,600/-
Total fixed cost		6,600/-
Operating cost		
Fuel consumption	-	1,500/- (15 litre @100/- per litre)
Labour charge (in month)	9,000/-(@300/- per day (unskilled))	12,000/- (@400/- per day (Semiskilled))
Repair and Maintenance	-	1,500/-
Total operating cost		15,000/-
Total cost	9,000/-	21,600/-
Capacity (kg/h)	5	20
Total capacity per day (kg)	20	80
Quantity of jamun harvested per month (kg)	600(@20 kg/day × 30 days)	2400(@80 kg/day × 30 days)
Cost of harvesting per kg of jamun	15/-	9/-

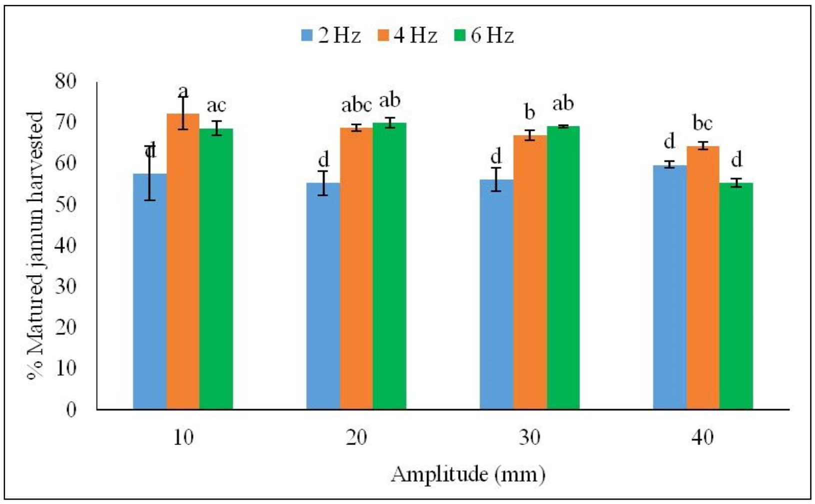

Fig 5: Effect of shaking amplitude and frequency on percentage matured jamun harvested.

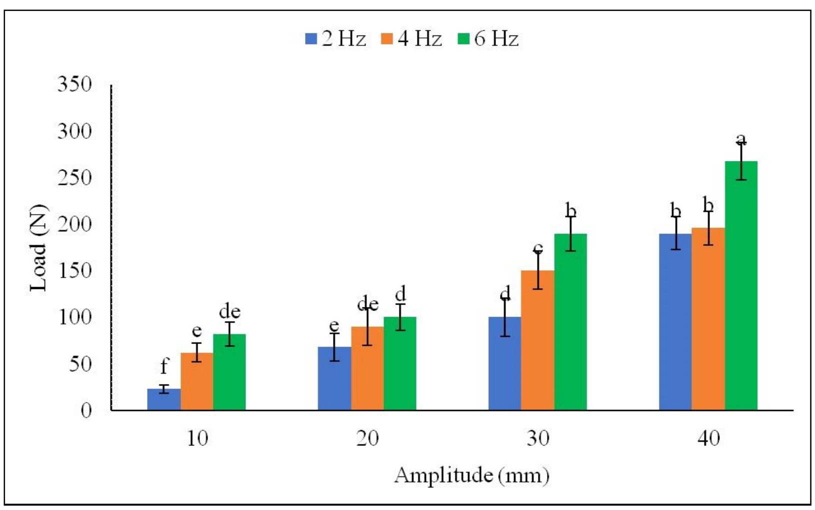

Fig 6: Effect of shaking amplitude and frequency on load on limb.

O'brien *et al.* (1983) reported shaking amplitude of 25-40 mm and frequency of 15-20 Hz for almond fruit. Different shaking amplitude were reported by various workers for harvesting different crops such as 50 mm for almond and Pistachio nut (Polat *et al*., 2007), 40 mm for apricot (Erdogan *et al.,* 2003). However, shaking frequency of 15-20 Hz were reported by the researchers for harvesting almond, apricot and pistachio nut in mechanical shakers. The higher value of shaking frequency was probably due to the higher fruit detachment force for almond (10-22 N) as compared to jamun (4.48 to 5.43 N).

Comparison of mechanical and manual harvesting

The capacity and cost of harvesting by manual and mechanical method are given in Table 4. The capacity of manual and mechanical harvesting of Jamun are 5 and 20 kg/h, respectively. The total cost of operation for mechanical harvesting was Rs. 21,600/-, whereas it was Rs. 9000/- for manual harvesting. The cost of harvesting of jamun by the developed harvester was found to be approx. Rs. 9/- as compared to Rs. 15/- per kg fruit for manual harvesting.

CONCLUSION

A power operated jamun fruit harvester having 20 kg/h capacity was developed and the performance was tested. The shaking frequency and amplitude both had a significant effect on harvesting efficiency. The percentage of fruit removal increased with increase in shaking frequency and amplitude. The maximum harvesting efficiency (64.33%) and fruit removal (93.15%) was obtained at shaking amplitude of 30 mm and 6 Hz frequency. The FDF/W ratio decreased with increase in maturity stage of the fruit. The cost of harvesting of jamun by the developed harvester was found to be approx. Rs. 9/ - as compared to Rs. 15/- per kg fruit for manual harvesting.

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Conflict of interest

The authors have declared no competing interest.

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