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DEVELOPMENT AND PERFORMANCE EVALUATION OF PVC LEMON HARVESTER

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ABSTRACT

India is the leading lemon producer in the world today. India is the first in the world most production of lemon. The traditional harvesting method of lemon fruit is a labour intensive, tedious, time consuming as well as high loss. Due to declining labour availability, time consuming and increasing labour cost, it is mandatory to mechanize the fruit harvesting operation. Therefore, it was necessary to develop a device that should be simple, easy to assemble and disassemble, low cost and light in weight with a proper balance. Considering these facts, a harvesting device was developed and compared with the traditional harvesting device. The harvesting capacities of the developed harvesting device and traditional harvesting device were found to be 10.15 kg/h (290 no. of lemon/ha) and 8.93 kg/h (250.75 no. of lemon/ha), respectively. The harvesting capacity (no. of lemon/ha), there was an increase of about 13.66% (developed harvesting device 290 no. of fruits/ha and traditional harvesting device 250.75 no. of lemon/ha) by using developed harvesting device as compared to that of traditional harvesting device. The harvesting efficiency of the developed harvesting device and traditional harvesting device were found to be 97.8% and 93.91%. The harvesting losses of the developed harvesting device and traditional harvesting device were found to be 6.09% and 2.2%. The harvesting cost of the developed harvesting device and traditional harvesting device were found to be Rs 3.85 per kg and rs 4.22 per kg.

Key words : Harvesting, Harvesting capacity, Harvesting loss, Lemon, Lemon harvesting device.

Introduction

India with diverse soil and climate comprising several agro-ecological regions provides ample opportunity to grow a variety of horticulture crops. These crops form a signification part of total agricultural produce in the country comprising of fruits, vegetables, flowers and spices. Horticultural crops play a unique role in Indian economy by improving the income of the rural people.

Lemon (*Citrus limon*) or 'Nimbu,' as they are called in India, is the most important fruit all over the world and is famous for its refreshing and sour flavour and used in culinary preparations. It is well known for nutritional as well as its medicinal property for both in traditional and modern medicine. The pulp and rind are also used in cooking and baking. The juice of the lemon comprises of about 5% to 6% citric acid, with a pH of around 2.2, giving it a sour taste. It is also rich in vitamin C and contains smaller amounts of Vitamin B, particularly thiamine, riboflavin, and niacin. Its juice is also used for non-culinary purposes like cleaning and stain removal (Anonymous, 2022).

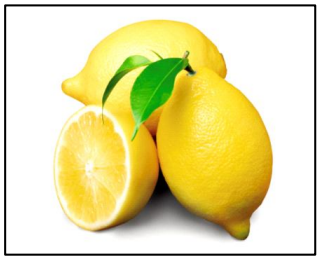
The lemon (*Citrus limon*) is a species of small evergreen trees in the flowering Myanmar or China. There are many types of lemons that grow across the country, but we're covering the 4 most popular ones below: (Anonymous, 2022).

1. **Nepali Round:** A successful cultivar in the states of South India. Despite the name, the Nepali round variety also has its origins in India.
2. **Lisbon Lemon:** This greenish-yellow, short-living variety is similar to Eureka (another lemon variety) in their elongated shape. The size of these

lemons is average, with a prominent nipple at the apex. Apart from this, they are quite acidic in nature.

3. **Kagzi Nimbu:** This variety will be the second one in securing Geographical indication (GI) tag after Manipur's Kachai Lemon. Kagzi has thinner rind, more juice and highest ascorbic acid content among all the lemon varieties known so far.
4. **Assam Lemon:** The name refers to the two types of lemons that growing in Assam, namely, Gol Nimbu and Kazi Nimbu. Gol Nimbu is round and sweet. Further, it is usually larger than other varieties. GI tagged lemon of Assam Kazi Nimbu, on the other hand, is juicier with an elongated oval shape.

(1) Nepali Round



(2) Lisbon Lemon

(3) Kagzi Nimbu

(4) Assam Lemon

Materials and Methods

This chapter deals with the procedure followed and materials used to achieve the objectives of the selected research problem. Manually operated lemon harvesting device was developed and tested for its performance and compared with existing/traditional manual method. The proposed lemon harvesting device was fabricated and tested at fruit research center and nursery Lalbaug, Junagadh Agricultural University, Junagadh.

Physical properties of Lemon

Physical properties of any fruit being the base for designing any device to work with that fruit, they were determined for the kagzi variety of lemon fruits.

Dimensions

The dimension of kagzi lemon fruits was consider in terms of length, breadth and thickness which are described as under Three principal axis of the fruits *i.e.* length, breadth and thickness were measured using digital vernier caliper. The measurements were taken keeping in mind that both the extreme ends were touched by the jaws of the caliper.

Size

The size of an irregular shaped fruits can be determined by equivalent diameter (D_e). The dimensions like length (l), breadth (b) and thickness (t) were measured on three major axis of the lemon. Randomly selected 25 lemons were procured from the field to the laboratory and their dimensions were measured using digital vernier caliper (Mohsenin, 1980).

Weight

Electronic balance having least count 0.1 was used to weigh the fruits. All the fruits were weighted one after the other.

Color

Visual observations were made for evaluation of color and were compared with the standard color charts. The final result was drawn through the reports of the judges.

Volume

Platform scale method was used to determine the volume of each type of fruits. Volume of lemon was measured by any number of fruits can be taken which can be accommodated in the breaker as shown in plate 3.4. Randomly ten ripe fruits from each category were selected and volume was measured for each fruit.

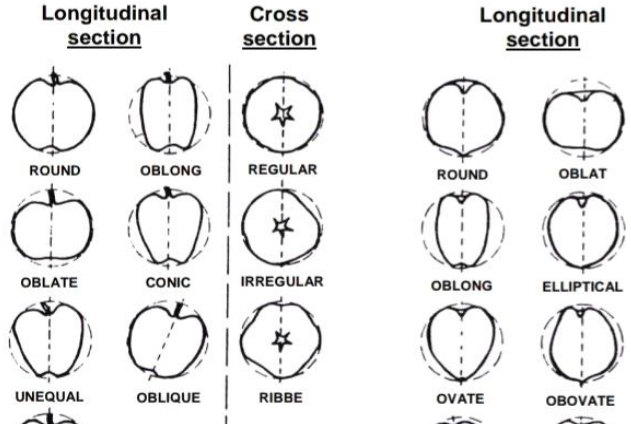


Fig. 2.1. Chart of Standard shape.

Physical Pro

Parties of Lemon Peduncle

Physical properties of lemon peduncle are used for design of cutting mechanism of harvesting device. Lemon fruits are required to cut with peduncle as well as stem. Generally lemon fruits were cut with peduncle.

Diameter and length of lemon peduncle

Diameter and length of lemon peduncle were measured using a vernier caliper as shown in Plate 3.6 having least count of 0.1 mm. length of lemon peduncle mean distance from fruits to cutting part of the fruit branch.

Cutting strength of lemon peduncle : Cutting strength of lemon peduncle is measured by spring balance.

Plant parameter

Parameter of lemon plant is used to make a design of any device to work with that fruit, they were measured for the kagzi lime variety of lemon fruits. Plant parameter *viz.*; row to row distance, plant to plant distance, plant height, plant canopy.

Row to row distance

A general survey of fruit research center and nursery Lalbaug was mad to collect the information regarding row-to-row distance. Measuring tape was used to measure row to row distance.

Plant to plant distance

Plant to plant distance was measured with the help of measuring tape.

Plant height

A general survey of fruit research center and nursery Lalbaug, was made to collect the information regarding lemon plant height. Telescopic staff was used for measurement of plant height.

Plant canopy diameter

Plant canopy diameter was determined by stone falling method. Stone was falling at the end of spreading branch of plant in both of N-S direction and measure the distance between two points. Measuring tape was used to measure the canopy diameter. Canopy diameter was used to determine overall plant canopy volume. Plant canopy diameter was measured in both N-S and E-W direction.

Design considerations

The device should be simple in design and construction and also requires minimum repair and maintenance. The device should be light in weight and easy to handle so as to be operated easily by single person. The device should be transported easily from one place to other. The device should cut the fruit at 360° angle around the periphery of cutting mechanism into the harvesting frame. The different harvesting losses should be minimum. The device should be low in cost and economical too.

Developed Lemon Harvesting Device

The manual picking of lemon fruit is done by simply removing fruits from the plant and putting them into a suitable container harvesting of fruit can be done appropriate maturity Lemon fruit should be harvested, when lemon attained dark green to greenish yellow colour. To minimize the damage, it is desirable to harvest the fruits with the stalk along with one or two leaves. This is very time consuming, tedious and more labour is required during harvesting season. While pulling a fruit, number of other fruits nearby along with the branch is pulled toward the labour and bounce back when the fruit cut from the branch. These action, detach many other fruits (ripe of unripe lemon while return travel of the branch. This detachment leads to the falling of fruits on the ground from the height or even more. The fruits that come down by these means get damaged when they fall on the ground. These damaged fruits create a loss to the farmers. So as to minimize this type of loss to the farmer a harvesting device was developed to harvest one fruit at a time. Keeping in view that, the harvesting device was developed such that pulling of fruits towards the operator be not needed to detach the fruit from the plant but the stem or peduncle be cut by means of V-shape of PVC.

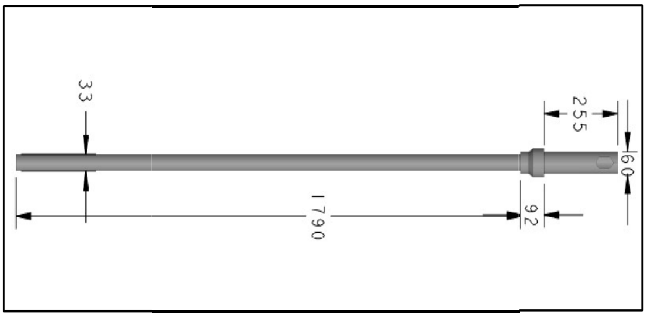


Fig. 2.2 : Front view of the Drawing of the Developed Harvesting Device.

(I) Parts of the developed device

A harvesting container was made by hollow pipe of PVC having 60.32 mm outer diameter, 51.76 mm inner diameter, 280 mm length and 4.28 mm thickness. Total periphery of harvesting container was 189.40 mm. the weight of harvesting container was 260 gm and shape of harvesting container was cylindrical.

(II) Supporting pipe

The supporting pipe was made from hollow PVC pipe because of its light weight. The total length of supporting pipe was 1828.8 mm (6 feet) having 33.40 mm outer diameter, 27.88 mm inner diameter and 2.76 mm thickness. The weight of supporting pipe was 844 gm and total periphery of supporting pipe was 104.87.

(III) Reducer

Reducer was providing for connecting the harvesting container with the supporting pipe. Reducer was made from PVC of 92 mm length. 33.40 inner diameter, 42.82 mm outer diameter and 4.71 mm thickness, where supporting pipe was connected with reducer. 60.32 mm inner diameter, 71.6 mm outer diameter and 5.64 mm thickness, where harvesting container was connected with reducer.

Specifications of the developed lemon harvesting device : Weight of the developed harvesting device: Harvesting device should be light in weight for easy to operate and handle while harvesting of lemon fruits. Hence lightweight materials were used for fabrication of the device. Weight distribution was shown in Table 2.2.

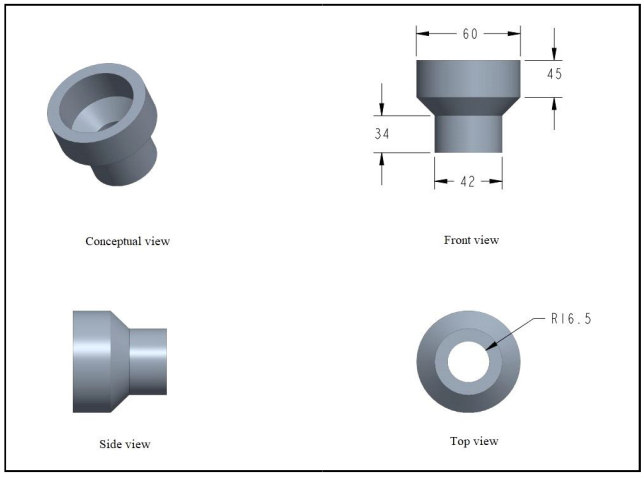


Fig. 2.2 : A view of the Drawing of the Reducer.

Performance Evaluation of the Developed Device: The efficiency or the capacity of the device can be evaluated by its performance in the actual condition i.e., field. So as to evaluate the performance, the developed lemon harvesting device was operated in the field and compared with traditional harvesting device. Dependent parameters were *viz.*, harvesting capacity (kg/h), harvesting capacity (No. of fruits/h), harvesting losses (percentage), harvesting efficiency (percentage) and cost of harvesting (Rs/kg).

Harvesting Methods

During field test two methods are perform i.e. (i) Traditional and (ii) harvested by developed device. The traditional harvesting device is such that the lemon that seems to be ready to ripen is taken by the device and lemon itself is pulled on ground surface, by this action the peduncle of the lemon is detached from the stem. Moreover, collecting on ground lemon takes time and labour has to drop the collected fruits into fruit collecting basket one by one. It was found that, these methods were very time consuming and tedious with more labour requirement during harvesting. Sometime lemon tree thorn is penetrating in the lemon, its causes to start spoil out the lemon. View of harvesting lemon and traditional harvester is shown in plate 3.19 and 3.20. Harvesting of lemon using the developed device and harvested lemon is illustrated in Plate 3.21, 3.22 and 3.23. As depicted in

Table 2.1 : Specifications of the Developed Lemon Harvesting Device.

S. no.	Particulars	Specification
1.	Overall dimensions	
	Length (mm)	2140.8
	Total weight (g)	1236
2.	Harvesting container (hollow PVC pipe)	
	Length (mm)	300
	Outer diameter (mm)	60.32
	Inner diameter (mm)	51.76
	Pipe thickness (mm)	4.28
	Total periphery (mm)	189.4
	Material	PVC
	Weight (g)	260
3.	Supporting pipe (hollow PVC pipe)	
	Length (mm)	1828.8
	Outer diameter (mm)	33.4
	Inner diameter (mm)	27.88
	Pipe thickness (mm)	2.76
	Total periphery (mm)	104.87
	Material	PVC
	Weight (g)	844
4.	Reducer	
	Length (mm)	92
	Outer diameter 1" side (mm)	42.82
	Outer diameter 2" side (mm)	71.6
	Inner diameter 1" side (mm)	33.4
	Inner diameter 2" side (mm)	60.32
	Reducer thickness 1" side (mm)	4.71
	Reducer thickness 2" side (mm)	5.64
	Total periphery 1" side (mm)	134.45
	Total periphery 2" side (mm)	224.82
	Material	PVC
	Weight (g)	128

plate 3.21 the harvesting device was held with both the hands. The cutting mechanism as shown in Plate 3.22 cut the lemon from the peduncle and the harvested fruits could fall in the container. The container can hold 6 to 7 lemons. It is unloading into the fruit collecting basket after it is completely filled. The basket was kept at the desired place near the plant.

Field test

Field test parameter were *viz*. harvesting capacity (kg/ha), harvesting capacity (No. of lemon/ha), harvesting losses (percentage), harvesting efficiency (percentage) and cost of harvesting (Rs/kg).

Harvesting capacity

Total amount of harvested lemon per unit time was considered as harvesting capacity. Number of harvesting lemons per unit time was also considered as harvesting capacity.

Harvesting losses

Harvesting losses was calculated based on weight of particular harvesting loss per unit time. Weight of mechanical damage, unripe harvested and ripe or unripe lemon falling on the ground per unit time could be considered as harvesting losses.

(I) Mechanical damage

The lemon having damage (cut due to blades) by means of the device was considered to have mechanical damage. The harvesting lemon were weighed and then the lemon having this type of damage were separated out from the lot of harvested lemon and weighted using simple balance.

(II) Unripe harvested

During the harvesting operation there are changes of lemon which may not reached the stage of initiation of ripening may also be harvesting due to lack of that keen visibility from the ground. This type of lemon was considered as unripe harvested. Unripe and ripe lemons were separated by careful observation and they were weighed.

(III) Ripe or unripe falling on the ground (spilled out lemons)

During the harvesting operation some ripe or unripe lemon fall on the ground due to jerk (pulling action) by manual picking as well as by developed device. This lemon was considered as spilled out lemon. The total harvested lemon as well as the spilled lemon out lemon was weighed separately.

Cost of harvesting

The cost of harvesting (Rs/kg) was determined using weight of total harvested lemon (kg) and the man-hour required for harvesting those lemon. Fixed cost and variable cost for both harvesting methods were calculated separately using straight line method (Sahay, 2004).

Results and Discussion

This chapter presents the analysis and interpretation of experimental results of all the phases of the study. Physical properties of lemon fruits, the detailed design dimension and field performance results of the developed lemon harvesting device and its comparison with traditional harvesting method (manual picking) are discussed step by step.

Physical Properties of lemon

The physical properties of lemon of kagzi variety were determined. Free flow of fruit through a container is depending on dimension, size, sphericity and shape. For efficient operation of the developed lemon harvesting device, important physical properties viz. dimension, size, equivalent diameter, sphericity, shape, weight and volume were determined.

Dimension

The dimension of lemon was considered in terms of length, breath and thickness. Three principles axes of the fruits i.e. length, breadth and thickness were measured using digital vernier caliper. The average values of length, breadth, and thickness of lemon fruit were determined as 41.30 mm, 40.35 mm, 39.56 mm, respectively.

Size

The size of a fruits of irregular shape can be determined by equivalent dimension (D_e). A sample of 25 fruits was taken to calculate equivalent diameter (D_e) of the fruit by using the formula given in section 3.1. An average equivalent diameter of lemon fruit was found as 40.39 mm using average values of length, breadth and thickness of lemon fruit.

Sphericity

Sphericity was determined to define the shape of lemon fruits. A sample of 25 fruits was taken to calculate the sphericity of the fruit by using the formula given in section 3.2. Average sphericity was obtained as 0.98. On the basis of sphericity, the shape of lemon fruits falls under the ovate category.

Shape

The shape of the actual fruit was visually observed and compared with the shape in the charted standard shape and based on visual observation the shape observed is round to ovate.

Weight

Weight of fruits of lemon fruit was determined by

Table 2.2 : Weight of the developed harvesting device.

Portion	Parts of device	Weight (g)
Upper portion	Harvesting container	260
Middle portion	Reducer	128
Lower Portion	Supporting pipe	844
Total weight		1232

Table 3.1: Physical Properties of Lemon

S. no.	Name of physical properties		Minimum	Maximum	Average
1.	Size	Length (mm)	35	47.33	41.3
		Breadth (mm)	34.58	47.08	40.35
		Thickness (mm)	34.01	46.25	39.56
		Equivalent diameter (mm)	34.53	46.88	40.39
2.	Sphericity (Ø)		0.91	0.99	0.98
3.	Weight (g)		26.48	46.2	35.65
4.	Volume of lemon (cm^3)		24.5	41.5	33.6

Table 3.2 : Physical property of lemon peduncle.

S. no.	Name of physical property of lemon peduncle	Minimum	Maximum	Average
1.	Diameter (mm)	2.26	2.83	2.51
2.	Length (mm)	7.47	8.61	7.91
3.	Strength (kg/f)	2.5	3.5	2.9

Table 3.3 : Lemon plant parameters.

S. no.	Lemon plant parameters	Minimum	Maximum	Average
1.	Row to row distance (m)	5	5	5
2.	Plant to plant distance (m)	5	5	5
3.	Plant height (m)	2.5	4.1	3.49
4.	Plant canopy diameter (N-S direction) (m)	2.9	5.3	4.09
5.	Plant canopy diameter (E-W direction) (m)	3.1	5.1	4.12

taking 25 numbers of samples. The weight of fruits varied in the range of 26.48 g to 46.20 g. An average value of single fruit was obtained 35.65 g.

Colour

Visual observations were made for evaluation of colour and were compared with the standard colour charts and based on visual observation the colour observed of lemon fruit was dark green to yellowish green.

Volume

Volume of lemon fruit were determined using the formula according given in section 3.3 by taking 10 samples. The volume of lemon fruit was found ranging from 24.5 cm^3 to 41.5 cm^3 with an average value of 33.6 cm^3.

Physical Properties of Lemon Peduncle

The physical properties of lemon peduncle were determined. Design of cutting mechanism of harvesting device is depends on diameter, length and cutting strength of lemon peduncle. For efficient operation of the developed lemon harvesting device, important physical properties of viz. diameter of lemon peduncle, length of lemon peduncle and cutting Strength of lemon peduncle were determined.

Diameter and length of lemon peduncle

Peduncle diameter and length of lemon fruit were determined by taking 5 numbers of samples. The diameter of lemon peduncle varied in the range of 2.26 mm to 2.83 mm. An average value was obtained 2.51 mm. The length of lemon peduncle varied in the range of 7.47 mm to 8.61 mm. An average value was obtained 7.91 mm.

Strength of lemon peduncle

Cutting strength or applied force of lemon peduncle was determined by taking 5 numbers of samples and which is used to determine stress required to cut lemon peduncle by harvesting device. The Cutting strength of lemon peduncle varied in the range of 2.5 kg/f to 3.5 kg/f. An average value was obtained 2.9.

Plant Parameter

Parameter of lemon plant was measured. Plant parameter viz. row to row distance, plant to plant distance, plant height and plant canopy diameter were measured and depicted below.

Row to row distance

Row to row was measured with measuring taps. Row

Table 3.4 : Harvesting Capacity, Efficiency, Losses.

S. no.	Test parameters	Traditional device	Developed device
1.	Harvesting capacity (kg/ha)	8.93	10.15
2.	Harvesting capacity (No of harvested lemon /ha)	250.75	285
3.	Harvesting efficiency (%)	93.91	97.80
4.	Total loss (kg/h)	0.543	0.222
5.	Total harvesting loss (%)	6.09	2.20

Table 3.5 : Harvesting cost.

S. no.	Harvesting method	Cost(Rs/kg)
1.	Traditional harvester	4.22
2.	Developed harvester	3.85

to row distance was measured 5 m and average distance between row to row was found 5 m.

Plant to plant distance

Plant to plant distance was measured with the help of measuring tape. Plant to plant distance was measured 5 m and average distance between plant to plant was obtained 5 m.

Plant height

Plant height was measured with the help of telescopic staff. Plant height was varied in the range of 2.50 m to 4.10 m and average height of 3.49 m.

Plant canopy diameter

Canopy diameter for lemon plant was measured with the help of measuring tape and stone. Canopy diameter (N-S direction) was varied in the range of 2.90 m to 5.30 m. An average value of plant canopy diameter (N-S direction) was found 4.09 m. Canopy diameter (E-W direction) was varied in the range of 3.10 m to 5.10 m. An average value of plant canopy diameter (E-W direction) was found 4.12 m.

Field Test

The field performance of the traditional harvesting method and the developed harvesting device were evaluated based on harvesting capacity (kg/h and No. of Fruits/h), harvesting losses (%) and harvesting cost Rs par kg.

Harvesting capacity (kg/h)

The harvesting capacity (kg/h) was determined by using the formula given in section 3.8 taking 8 numbers of observations. Table 3.4 shows harvesting capacity (kg/h) for both types of harvesting methods i.e. traditional harvesting device and developed harvesting device.

Harvesting cost (Rs/kg)

Harvesting cost (Rs/kg) of lemon was determined for both types of harvesting methods. The harvesting cost (Rs/kg) was determined by using the formula given in section 3.14 taking 8 numbers of observations. The results of harvesting cost are presented in Table 3.5.

The harvesting cost for the harvesting methods, traditional harvesting device and developed harvesting device were observed 4.22 and 3.85 Rs/kg. It reveals that decrease in the cost by 8.77% was observed in harvesting cost using developed harvesting device as compared to that of the traditional harvesting device**.**

Ergonomics Design

The developed harvesting device is light in weight with proper balance, its parts easily assembled and disassembled, required minimum training for developed and operate device. This developed device according to size and weight easily operate by farmer. Developed device is user-friendly equipment. It's simple mechanism and intuitive design allowed farmers to quickly understand and adapt to the harvester.

Conclusion

1. Harvesting performance of the traditional harvester and the developed harvester were evaluated based on their harvesting capacity, harvesting losses and harvesting cost.
2. The harvesting capacity (kg/ha) of traditional harvester and developed harvester were measured as 8.93 kg/h and 10.15 kg/h respectively. Harvesting capacities was on higher side for developed harvesting device as compared to that of traditional harvesting device.
3. The harvesting capacity (No. of lemon/ha), there was an increase of about 13.66 % (developed harvesting device 285 No. of lemon/h and traditional harvesting device 250.75 No. of lemon/ha) by using developed harvesting device as compared to that of traditional harvesting device.
4. The harvesting losses (kg/ha) of traditional harvester and developed harvester were measured as 0.543 kg/h and 0.222 kg/ha respectively. Harvesting losses was on lower side for developed harvesting device as compared to that of traditional harvesting device.
5. The harvesting losses (%) of traditional harvester

and developed harvester were measured as 6.09 % and 2.20 % respectively, there was decrease of 63.83% in harvesting losses (%) of developed harvesting device as compared to that of traditional harvesting device.

6. The harvesting efficiency (%) of traditional harvester and developed harvester were measured as 93.91% and 97.80% respectively, there was increases of 4.14 % in harvesting efficiency (%) of developed harvesting device as compared to that of traditional harvesting device.
7. The harvester design and mechanism ensured gentle handling of lemons, resulting in minimal fruit damage. The PVC pipes provided a soft and non-abrasive surface for contacting the lemons, reducing the risk of bruising, scarring, or other forms of damage.
8. The use of developed harvesting device is found to minimize harvesting cost and harvesting losses. It also increased the overall efficiency of harvesting along with the harvesting capacity.
9. The developed harvesting device is light in weight (1236 g) with proper balance, its parts easily assembled and disassembled, required minimum training for developed and operate device. This developed device according to size and weight easily operate by farmer.
10. Developed device is user-friendly equipment. It's simple mechanism and intuitive design allowed farmers to quickly understand and adapt to the harvester.

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