Development and performance evaluation of manual harvesting device for kinnow (Citrus nobilis X citrus deliciosa) fruit

Divakar Chaudhary, Abhay Kumar Mehta and Kamendra

Abstract
Harvesting is one of the most important activities in fruit production, handling and preservation cycle. Fruits are generally damaged due to lack of a suitable harvesting device. A study was conducted to survey the existing traditional harvesting methods utilized for Kinnow fruits and to identify associated physical and physiological problems occurred in Kinnow fruit harvesting. Based on the identified problems and to reduce physical working stress of farm workers in harvesting operation an Ergo-Friendly harvesting system was developed, which comprised of aluminium telescopic pipe, clutch operated cutting mechanism, micro-camera, display, battery, fruit collection net and ergonomically designed harness. The more output in terms of harvested fruits obtained in traditional harvesting method than improved method but harvesting of Kinnow fruit from traditional method leads to a high damage (8.80 percent) whereas it was nil for the developed method. Using developed method harvesting leads to a profit of Rs 42,059/hectare. This makes the machine economically better than traditional method.

Keywords: performance evaluation, citrus deliciosa, Citrus nobilis

Introduction
India being the home of many citrus species, its cultivation is spread over 0.95 million hectares with the production of 11.66 million tonnes (Anonymous, 2016) [1]. Among citrus group, the Kinnow mandarin occupies a unique place in the fruit industry of India. In India, citrus fruits ranks third in production after banana and mango. Among citrus crops, mandarin orange (Kinnow mandarin, Nagpur, Khasi, Darjiling) covers largest area followed by sweet orange (Musambi, Pineapple, Blood Red and Jaffa) and Acid lime. Among these, Kinnow mandarin bears highest place in the production, productivity, juice content and fruit quality. The acreage under Kinnow cultivation is being expanded in arid and semi-arid zones due to the growing market demand in domestic and International markets. Commercially, it is grown in Punjab, Haryana, northwestern parts of Rajasthan and Uttar Pradesh.

In Haryana, its production is estimated at 2.31 lakh tonnes from 17,402 hectare area (Gera, 2014) [8]. The interest of farmers in adoption of Kinnow cultivation is increasing day by day due to suitable agro-climatic conditions, higher crops yield and demand in International market.

Harvesting of Kinnow
Harvesting is one of the most important activities in fruit production, handling and preservation cycle. Fruits are generally damaged due to lack of a suitable harvesting device. Presently, fruits harvesting operations in the state is being done traditionally by hand picking or by climbing on ladder on tree directly. These traditional methods are labour, time and drudgery oriented and also affects the quality of the fruit and reduced margin of profit for the farmers. Moreover, acute neck and shoulder pain to the workers has been reported during fruit picking at the upper periphery of the tree that restrict them for continuous work. Workers also got injuries during operation either falling from the tree or ladder. Hence an ergonomically designed manual fruit harvester is required to overcome these problems.

Mechanical and automatic harvesters have been developed or attempted by many researchers. Mechanical harvesting systems are designed to achieve mass removal of the fruit during the harvesting season. This method has been practiced using such as canopy/limb/truck shaker or air blast with chemical mechanics of abscission as pre-harvest agents to loosen the mature fruits.
There are few drawbacks in mechanical harvesting system viz. the quality and size selection, the damage to the fruit and trees in some cases. However, the mechanical system operates blind when it come to removing quality ripe fruit. Almost in all these methods, damages to the fruits, leaves and consistency of the performances are the major issues. Manual harvesting has many advantages compared with the mechanical harvesting of most fruit crops. The most important advantage is visual image processing ability which enables workers rapidly to detect fruit suitable for harvest and direct their hand to the fruit selected for detachment.

Material and Methods
In this study, a prototype of harvesting tool was developed for citrus fruits. The developed prototype was evaluated under field condition for its performance. A manual fruit harvesting device was designed and fabricated in the workshop of the department of Farm Machinery and Power Engineering, College of Technology and Engineering, Udaipur and tested at the farmer’s field, in the village Dubeta, Hisar (Haryana).

Manually kinnow harvesting operations
The study deals with the survey of existing traditional harvesting methods utilized for Kinnow fruits in Hisar region. The traditional method of Kinnow harvesting generally done by manual picking of fruits situated upto hand reach height while another method is bamboo stick having hook at its extreme and known as “ankdi” method. A bamboo stick of 30-40 mm diameter and 1500-2000 mm long is mostly utilized for harvesting of fruits. A plastic bucket of opening diameter with 310 mm and height 500 mm is generally used for collection of fruits.

Fabrication of developed harvesting system
The construction and the main components of harvesting system are explained in the subsequent text.

Extension Pipe
A long hollow aluminium telescopic pipe of 3530 mm length is designed to provide a combination of long reach and high cutting power of multiple fruits. Broadly, it consists of three light weight aluminium pipes which are attached to each other with the help of clamps. The length of the first, second and third pipes are 1500 mm, 895 mm and 867 mm, respectively. First and second pipe are attached to each other with the help of a clamp, these can be folded for ease of transportation and storage by loosening up the clamp. The second pipe imbibes the third one within itself with a lock button, to adjust the height of third pipe there are five adjustable options with an automatic lock which needs to be slightly pushed, to move in either direction or needs to be left at the hole where it is to be fixed. These five holes provide the user five different fixed heights to perform the cutting operation as per the tree height or requirement. The third pipe, shortest one, once brought forth can be used to mount camera and fruit collecting basket. The aluminium rod has support system of stands for battery and display, one hang grip and two butterfly locking mechanism for mounting camera and attaching fruit collecting net. Furthermore, this entire apparatus is mounted on the body of farmer through a clamp and nut bolt mechanism which is attached to ergonomically designed and fully supported belts because of which it can be rotated at 360° to easily harvest fruit at any height and angle. These features make the entire machine user-friendly, increases efficiency and provide a cheap option to wide strata of farmers world-wide.

Cutting mechanism
For cutting mechanism a pruning secateurs was used, it consist of cutters (scissor) and support blade, one of the blade was fix and other was movable as shown in Fig.4. It was mounted on upper end of the extension pipe. The fruit guide has been provided at exact place, to easily catch every fruit in the cutting zone. The power to cutting mechanism is transmitted via steel wire through inner side of the extension pipe. The cutter is made up of stainless steel and is provided with steel strip to further support and efficiently perform the function of cutting. To use it, hook the stainless steel lower jaw over the stem and pull the clutch handle on the end of the tool. The clutch drive pulls the tool’s steel blade through the stem. The blade has a low-friction coating to reduce the cutting force required, and to make it easier to keep clean.
Table 2: Dimensions of cutting mechanism

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Particular</th>
<th>Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Length of blade (mm)</td>
<td>80</td>
</tr>
<tr>
<td>2.</td>
<td>Material of cutting mechanism</td>
<td>Stainless steel</td>
</tr>
<tr>
<td>3.</td>
<td>Weight (kg)</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Micro-camera
The function and requirement of camera is to locate the fruit on the trees. It may be mounted on very easily, through butterfly locking mechanism on the extension pipe, just before the cutter. This is a compact size effective and handy camera of 4 megapixels, which can display the fruit on the screen with absolutely no difficulty provides hassle free and easy harvest. It is powered by a battery which is its power source.

Table 3: Specifications of micro-camera

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Specifications</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Resolution of IP Camera</td>
<td>HD</td>
</tr>
<tr>
<td>2.</td>
<td>Lens angle of IP Camera</td>
<td>170</td>
</tr>
<tr>
<td>3.</td>
<td>Power</td>
<td>12V</td>
</tr>
<tr>
<td>4.</td>
<td>Weight (kg)</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Fruit collection net
The collecting basket with a rectangular metallic frame uses polyester cloth to ensure the safe harvest and zero damage of fruit. This polyester cloth has a length of 100 mm which is permanently attached to the metallic frame. The further piece of 2900 mm cloth can be removed and reattached as per the requirement. The reattach capability of cloth through zip lock system makes it easy to carry and can be used to assemble the machine within no time.

Display
It makes the cumbersome cutting process easy by reducing neck angle thus alleviating the pain and enhancing capability of operator. This derives power from battery. The display is fitted on the telescopic pipe in such way that its height can adjust according to the height of operator.

Table 4: Specification of display

<table>
<thead>
<tr>
<th>S. No</th>
<th>Specifications</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Display size (mm)</td>
<td>109.22</td>
</tr>
<tr>
<td>2</td>
<td>Display type</td>
<td>Color monitor</td>
</tr>
<tr>
<td>3</td>
<td>Power</td>
<td>12V</td>
</tr>
</tbody>
</table>

Clutch
It is an aluminum handle with 180-degree rotatable angle and non-slip soft grips, is an optimum and potent cutting tool in the hands of a farmer. The power to cutting mechanism is transmitted through clutch via steel wire through inner-side of the extension pipe. This makes the cutter easy to use. To avoid any injury when the cutter is not operational the clutch have a lock to close the blades of cutter and their movement.

Battery and Charger
The camera system is powered with the 12 V battery for continuous and safe power supply for 8 to 10 hours. The charger can fully charge it in 3 to 4 hours. It weights around 600 gms. The battery is attached to the machine through the battery rig, near the display, on first pipe.
This is an ergonomically designed belt which equally distributes the weight of the entire apparatus on the body of the operator. It is extremely comfortable and highly user-friendly as it can be adjusted from both shoulders and waist. Furthermore, a strap attaches shoulder to extension pipe which ascertains more grip and increases operability.

**Performance evaluation of equipment**

The parameters that are considered for performance evaluation are Output (kg/h), labour required (man-hour/kg), fruit damage (%), Cost of equipment (Rs/kg) and Cost economics.

**Cost of Operation**

The total cost of the machine was determined based on fixed and variable cost by considering the life of machine, annual use, wages rate and payback period was also considered.

**Results and Discussion**

**Performance evaluation of Kinnow fruit harvesting device**

The performance evaluation of developed fruit harvesting device was done by using the two methods such as developed method and traditional method. The developed method compared with traditional method by using the four parameters like Output (kg/h), Labour required (man-hour/kg), Fruit damage %, Cost of equipment (Rs/kg) and Cost economics.

**Output**

Output obtained during harvesting operation is presented in Table 5.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Traditional method</th>
<th>Developed method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>59.67</td>
<td>52.33</td>
</tr>
<tr>
<td>2</td>
<td>57</td>
<td>51.33</td>
</tr>
<tr>
<td>3</td>
<td>53.33</td>
<td>46.67</td>
</tr>
<tr>
<td>4</td>
<td>53.33</td>
<td>46</td>
</tr>
<tr>
<td>5</td>
<td>49.33</td>
<td>45.67</td>
</tr>
<tr>
<td>6</td>
<td>50.33</td>
<td>44.33</td>
</tr>
<tr>
<td>7</td>
<td>51</td>
<td>42.33</td>
</tr>
<tr>
<td>8</td>
<td>53</td>
<td>44.67</td>
</tr>
<tr>
<td>9</td>
<td>58.67</td>
<td>49.33</td>
</tr>
<tr>
<td>10</td>
<td>55.33</td>
<td>44.67</td>
</tr>
<tr>
<td>Avg.</td>
<td>54.099</td>
<td>46.733</td>
</tr>
</tbody>
</table>

The maximum output ranged from 49.33 to 59.67 kg/h and 42.33 to 52.33 kg/h for harvesting of Kinnow fruits by traditional and developed device, respectively. It can be seen from above table that the mean output was lower in developed device than traditional method but the drudgery and discomfort is more in traditional method of harvesting of Kinnow.

Output of 57.28 kg/h was observed in the traditional harvesting of orange fruit whereas it was 42.48 kg/h for improved fruit harvesting as reported by Sabale et al. (2016). In order to observe the effect of operation on the output and its significance, the statistical analysis conducted and interaction between time and method was found non-significant because the output is maximum in morning mainly because of fervor and freshness during that time and it decreases as the day passes by, the table is presented below.

**Fruit damage**

Though the output of traditional method of harvesting is high but the damage to fruit from developed method is nil as shown in Table 8.
Table 8: Fruit damage with different methods of fruit harvesting

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Traditional method</th>
<th>Developed method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Harvested fruit (kg)</td>
<td>Damage fruit (kg)</td>
</tr>
<tr>
<td>1</td>
<td>59.67</td>
<td>5.67</td>
</tr>
<tr>
<td>2</td>
<td>57.00</td>
<td>6.00</td>
</tr>
<tr>
<td>3</td>
<td>53.33</td>
<td>4.67</td>
</tr>
<tr>
<td>4</td>
<td>53.33</td>
<td>5.00</td>
</tr>
<tr>
<td>5</td>
<td>49.33</td>
<td>5.33</td>
</tr>
<tr>
<td>6</td>
<td>50.33</td>
<td>5.00</td>
</tr>
<tr>
<td>7</td>
<td>51.00</td>
<td>4.33</td>
</tr>
<tr>
<td>8</td>
<td>53.00</td>
<td>3.67</td>
</tr>
<tr>
<td>9</td>
<td>58.67</td>
<td>3.33</td>
</tr>
<tr>
<td>10</td>
<td>55.33</td>
<td>4.67</td>
</tr>
<tr>
<td>Avg</td>
<td>54.099</td>
<td>4.76</td>
</tr>
</tbody>
</table>

The maximum damage ranged from 6.00 to 3.33 kg/h for harvesting of Kinnow fruits by traditional technique and was almost negligible in developed method, respectively. Fruit damage of 8.00 kg/h was observed in the traditional system of orange fruit harvesting device as reported by Sabale et al. (2016). Fruit damage was observed during Kinnow fruit harvesting operation is analyzed statistically. The ANOVA is presented in Table 9.

Table 9: Anova for Damage in Kinnow harvesting operation

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>C.D</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor A(Time)</td>
<td>2</td>
<td>0.608</td>
<td>0.304</td>
<td>0.199</td>
<td>0.00161</td>
</tr>
<tr>
<td>Factor B(Method)</td>
<td>1</td>
<td>92.027</td>
<td>92.027</td>
<td>0.162</td>
<td>0.00000</td>
</tr>
<tr>
<td>Interaction A×B</td>
<td>2</td>
<td>0.608</td>
<td>0.304</td>
<td>0.281</td>
<td>0.00161*</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>0.232</td>
<td>0.023</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>93.663</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significance 1 per cent

Statistical analysis (Table 9) indicated that the time and method was significant at 1% level of significance and interaction between time and method also at 1% level of significance in both the methods of harvesting.

Table 10: Two way mean table

<table>
<thead>
<tr>
<th></th>
<th>B1</th>
<th>B2</th>
<th>Mean A</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>4.967</td>
<td>0.000</td>
<td>2.483</td>
</tr>
<tr>
<td>A2</td>
<td>4.067</td>
<td>0.000</td>
<td>2.033</td>
</tr>
<tr>
<td>A3</td>
<td>4.533</td>
<td>0.000</td>
<td>2.267</td>
</tr>
<tr>
<td>Mean B</td>
<td>4.522</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

Table 10 shows that there is a significant difference in damage of fruits between the time and method, the highest damage was obtained in morning (A1) and the lowest in the afternoon (A2) in traditional method as the quantity of fruit damaged during harvesting was directly proportional to the amount of fruit harvested.

Fig 12: Mean Damage in different Kinnow fruit harvesting

The fruits damage was almost negligible in developed method as compared to the traditional method. Traditional harvesting method resulted highest fruits damage i.e. 4.522 kg/h.

Table 11: Per cent of fruits damage during harvesting operations

<table>
<thead>
<tr>
<th>Methods of fruits harvesting</th>
<th>Traditional method</th>
<th>Developed method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruits damage (per cent)</td>
<td>8.80</td>
<td>0</td>
</tr>
</tbody>
</table>

The fruits damage was almost negligible in developed method as compared to the traditional method. Traditional harvesting method resulted highest fruits damage i.e. 8.80 per cent. In the traditional method the percentage of fruit damages due to wrong picking or using stick having hook at its one end to reach high tree-top fruits was higher. The more output in terms of harvested fruits obtained in traditional method than developed method but considerable damage to fruits observed in traditional method as compare to developed method.

Fruit damage of 17.22 percent and 13.95 percent was found in traditional harvesting method of Guava and Orange fruit respectively as reported by Wade et al. (2010) [13] and Sable et al. (2016).

Labour required

The number of man working hours required to harvest 10 kg of Kinnow by traditional and developed method was found to be 11 and 12.8 minutes, respectively, detail calculation is provided below:

For Traditional method:-
1 hr = 54.099 kg
1 min = 60 (Sec)
54.099(Kg)
1 Kg = 1.10 min

For Developed method:-
1 hr = 46.733 kg
1 min = 60 (Sec) 
46.733(Kg) 
1 Kg = 1.28 min

Cost of equipment
Cost incurred using the equipment for the harvesting of one Kg of fruit from traditional and developed method was 0.92 Rs/kg and 1.26 Rs/kg respectively, detail calculation is provided below:

For traditional
1. Total output / day = 54 kg / ha 
   = 54 × 8 
   = 432 kg / day
   = 432 × 12 (Rs / kg)
2. Income per day = 5,184 Rs / day
3. Labour charges = 400 Rs / day
   = 400
   = 50 Rs / hr
4. Cost = 50
   Output 54
   = 0.92 Rs / kg

For developed
1. Total output = 47 kg / hr
2. Marketable yield = 47 × 8
   = 376 kg / day
3. Total cost (fixed and variable) = 59.67 Rs / hr
4. Cost = 51.67
   Output 47
   = 1.26 Rs / kg

Economics of fruit harvester
Harvesting of Kinnow fruit from traditional method leads to a high damage whereas it was nil for the developed method. Using developed method harvesting leads to a profit of Rs 42,059/hectare detail calculation is provided below:

For traditional
1 acre = 132 plants
1 tree = 1.5 quintal (150 kg)
1 acre = 198 quintal (including 10 % losses)
Marketable yield = 178.2 quintal
1kg = 12 Rs
For 1 quintal = 1200 Rs
1 acre = 178.2 × 1200
= 2,13,840
To harvest 1 kg = 0.92 Rs
For 1 quintal = 0.92 × 100 = 92 Rs
198 quintal = 198 × 92 = 18216 Rs
Profit = 213840 − 18216
= 195624 Rs

For developed
Marketable yield = 198 quintal
1kg = 12 Rs
For 1 quintal = 1200 Rs
1 acre = 198 × 1200
= 2,37,600
To harvest 1 kg = 1.26 Rs
For 1 quintal = 1.26 × 100 = 126Rs
198 quintal = 198 × 126 = 24948Rs
Profit = 237600 − 24,948
=Rs 2,12652
Difference = 212652-195624=Rs17,028/acre.

By using the developed technique a profit of Rs 42,059 per hectare is attained.

Conclusion
Following conclusions can be drawn on the basis of results obtained:
1. Traditionally harvesting method for Kinnow found the most tedious and risky operation.
2. On the basis of results obtained the developed technique of fruits harvesting is much better than the traditional method and a high margin of profit is attained from using the developed method because the damage in the improved technique was nil, which makes the machine ergonomically as well as economically better than traditional method and hence it can be concluded that the suggested technology are feasible and highly recommended for farmers.

References