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RESEARCH ARTICLE

Development of an advanced mango picker with automatic sorting facility

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ABSTRACT

Harvesting is one of the most important activities in the post-harvesting life of mango and it is the most difficult work for workers to collect the fruit without any type of damage and quality compromise. Traditional pickers are examples of very simple and easily available harvesting tools but it increases fruit damage caused by fruit fall and latex stains. It requires additional effort from operators which may cause musculoskeletal disorders. Other available automatic pickers are costly in operation, unhandy, required skilled manpower, and involve significant initial investment. This paper exercises the problems related to generally-used harvesting tools and proposes a low-cost advanced mango picker for improving harvesting techniques and reducing the harvesting losses due to latex stain, latex burn, and fruit fall. This advanced mango picker facilitates mango harvesting by cutting its stalk at a certain length. After cutting the stalk, the harvested mango passes through a collecting basin and is conveyed to the ground level by a flexible hose for automatic sorting into different packs. The entire activity from cutting of stalk to sorting and packing to different packs is a human touch-less automatic process controlled by a microcontroller. Hence, it decreases the overall harvesting time and effort.

Keywords: Automatic sorting, fruit fall, latex stains, latex burn, mango picker

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INTRODUCTION

Mango is one of the very popular fruits worldwide not only due to its fascinating taste but also has many health benefits and economic importance. India is the largest mango-producing country and it produces almost half of the world's mango production (Mohamed, 2017). In India, 23 lakh hectares of land are used for mango cultivation and thousands of tons of mangoes are imported to many counties. In mango cultivation, harvesting is one of the most crucial activities where the main attention is paid to collecting the mangos without any type of damage or quality compromise. It is very essential to maintain product quality before reaching customers, particularly for exporting it abroad (Pise and Upadhye, 2018). Apart from handpicking, many mango harvesting tools are available like traditional handheld pickers, handheld pickers with cutting attachment(s) (Ratnakumar, 2013, Befikadu, 2014 and Sabale, et al., 2017), battery-operated handheld pickers (Kumar et al., 2022), self-propelled mobile platforms (Kolhe, 2010), tractor-operated hydraulic platforms (Thiyagarajan and Tajuddin, 2018), automatic fruit picking grader machine

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(Walsh, 2022), etc. These harvesting tools apply different harvesting techniques with different harvesting capacities. Generally, powered harvesting tools are costly and suitable for large harvesting requirements. But, for small and medium orchards, farmers prefer to use handheld pickers due to their cost, ease to use, and portability (Sabale et al., 2017). Therefore, almost all of the mango harvesting, here, is done by handheld pickers.

Many handheld pickers have been developed modifying the traditional picker. One of such pickers, a lightweight mango picker was manufactured to decrease fruit fall and latex bleeding (Mohamed, 2017). The system was designed to reach the top of the mango, up to 4 meters in height. The cutting mechanism was executed by contrarily rotating two circular saws in the inside direction. The design includes the cutting of the stalk at the correct length. A comparison of cutting efficiencies has been done with different teethed cutters. Results showed 95% efficiency with 100 teeth circular saw disc at the speed of 8.34 m/s. The position of the counter blade was fixed below the discs with overlapping 5 m to take the same efficiency. The picker can decrease the injured fruit percentage compared to the manual picker.

The DBAU has developed a trig-type cutting mechanism-based harvesting tool using low-cost local components, as shown in Fig. 1 (Ratnakumar, 2013). An ABS pipe, nylon basket, and lever-trigged detachable two blades have been used to keep the overall weight of one-n-half kg of a 5 ft. long picker. The University of Southeastern Philippines developed a modified Sigpao (picker), as shown in Fig. 2, by including an additional blade in the trig and pull mechanism of harvesting with the intention to reduce the common problems i.e., latex stain, latex burn, and fruit fall (Montepio, et al., 2016). A fruit picking trial was done to compare between conventional picker and a designed fruit picker and the result was indicating the latex stain, and fruit fall problems were reduced by over 90% and 85% by using the modified tools. Another mechanical fruit-picking stick has been designed and developed with improved grasping attachment for better shape adaptability of different fruits like mango, pomegranate, guava, etc. (Chandru, et al., 2018). The concept was initiated with the requirements of local farmers and its design get validated by Ansys before fabrication. A battery-operated harvesting device, as shown in Fig. 3 (a), has been designed by a team of MPUAT, Udaipur where an adjustable motor, a rotating blade, and a camera are fixed with the ring mounted at the tip of a telescopic pole (Kumar, et al., 2022). A Bluetooth display attached at the end of the pole is provided for visualization of the cutting operation by the operator. To power the 12V high-speed DC motor and other electronics components, a 1.5 kg 12V battery of 7.5A is used.

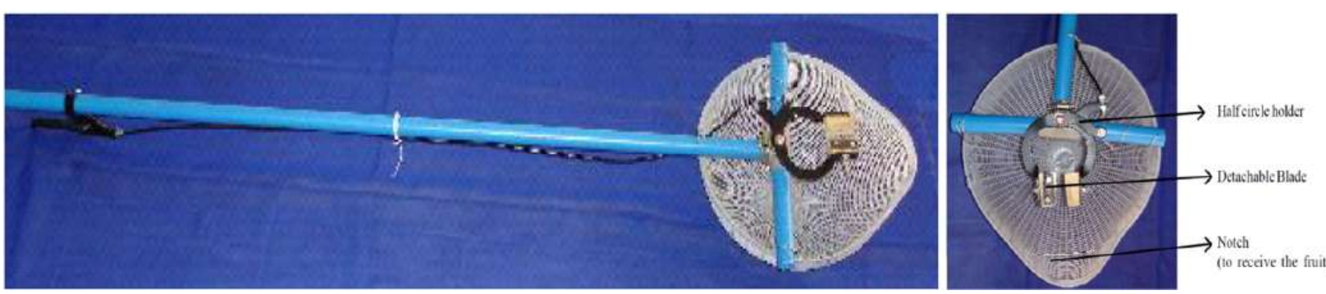

Figure 1: Handheld mango harvester developed by the Department of Botany, Andhra University (Ratnakumar, 2013)

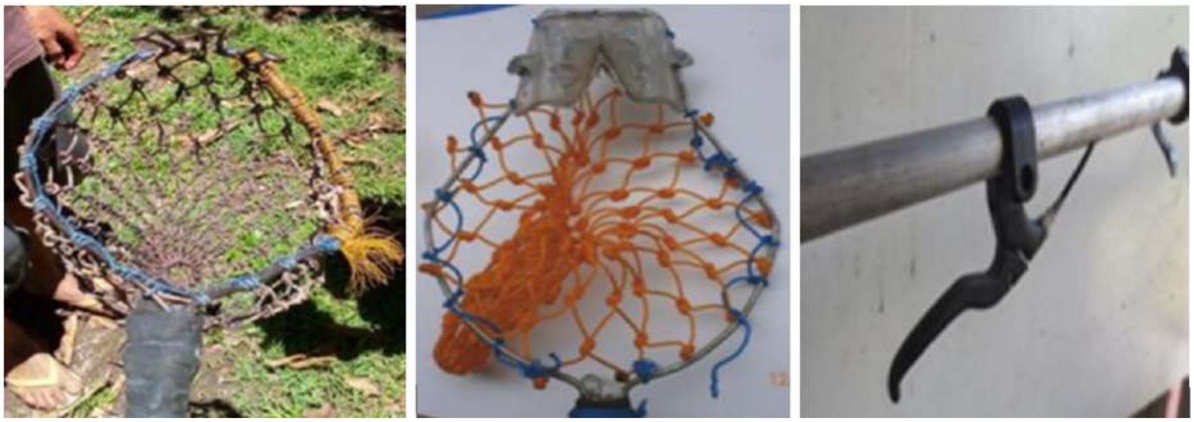

Figure 2: (a) Sigpao, and (b) Pull-n-trigger type Picker (Montepio, et al., 2016)

Figure 3: (a) Battery-operated handheld harvesting device (Jhala, et al., 2018), (b) Tractor-operated hydraulic platform developed by ICAR-IIHR, and (c) The world's first automated mango picking invented by Central Queensland University

ICAR-IIHR has developed a hydraulically lifted platform, as shown in Fig. 3(b), operated by a tractor to facilitate harvesting, pruning, and spraying operations of tall trees. The platform can be fixed to a variable height of up to 6 m to provide a 9-10 m harvesting height.

Grading of harvested fruits is also a significant activity among the post-harvesting activities. With the advancement in the picking mechanism, an automatic grading mechanism has also been included in harvesting tools. One such automatic grading of mangoes was proposed to inspect the standard of mangoes with the help of image processing and computer vision techniques (Sadegaonkar et al., 2013). This non-destructive grading solution utilizes the online digital image processing method. The aim was to find an alternative to manual grading to increase productivity in local agricultural industries. Another automatic grading system of mangoes works on the basis of their geometry and shape with the help of an 8-bit grey level XGA format color camera (Momin et al., 2017). The morphological classification is divided into three grades - large, medium, and small and the accuracy is satisfactory as reported. A new technique for correct grading was proposed by Pise and Upadhye which works depending on the size, shape, color, and surface pixel of mangoes (Pise and Upadhye, 2018). The machine learning method has been applied to define maturity and classify it into three grades – Red, Yellow, and Green. An SVM-based grading system was proposed to identify the ripeness of mangoes and categories them into four groups i.e., under ripen, perfectly ripen, over ripen with internal defects and over ripen without internal defects (Raghavendra et al., 2020). This classification approach exhibits around 88% better accuracy than the existing models.

Most recently, the Fruitions technology team of CQU designed a 4-armed harvester, as shown in Fig. 3(c), which works automatically based on the camera-captured image of a mango (Walsh, 2022). The trailer mounter harvesting modules are pulled by a Ute. The plane of the fruits is identified by the camera and fixed one of the arms holds the mango and rotates half-turn to retract. With a processing time of 5-6 seconds, the harvester attained 75% auto-identifying efficiency. The research work is in the prototype stage and is yet to be available commercially.

From the survey, it has been seen that almost all the harvestings of mango in India are being done using handheld traditional mango pickers. The handheld traditional mango pickers pluck the fruit by tearing its stalk from the base of the mango. As the stalk tears from the base, excessive latex squeezes reduce the self-life of mango apart from latex burnt. Additionally, this latex leaves a latex stain on the outer skin of the mango and caused latex burn. It lowers the export quality of the mango and decreases the market value. Another issue arises when the mango stalk tears from the base of the mango that is the latex sprinkled on the operators and the persons nearby. The sprinkled latex drops are harmful to human as it causes burning of the skin, rashes, and other types of skin problems. The sudden mango fall during harvesting from the other branch of the tree is another serious problem as the traditional pickers use a tear-off technique for plucking the mango from the tree and the jerking force transfers into other mangoes of the same branch and another branch. A significant number of mangoes get damaged by this phenomenon which is a serious loss. Apart from the above, traditional pickers require more harvesting time and additional effort which may cause musculoskeletal disorders (Boriboonsuksri et al., 2022).

The battery-operated handheld pickers introduced additional weight for the battery and components which need to be carried by the operators while harvesting (Jhala et al., 2018). The use of the camera and the display requires careful handling and regular maintenance. Charging of battery is an issue, after a certain interval it needs to be charged which interrupts the harvesting process. The tractor-operated hydraulic platform is used for harvesting mangoes from tall trees. It only provides the required height of the platform from where a worker can work or harvest. The automatic mango-picking device (robot) is an advanced machine with a large investment and is yet to available in the market. Therefore, the aim of the work is to design and develop a low-cost, user-friendly, advanced mango picker for small to medium farmers which can reduce latex stain, and latex burn and eliminate harvesting losses due to fruit falls and human hazards. It can reduce the overall harvesting time and effort which can be used by semiskilled people too.

PROPOSED SOLUTION

The proposed harvesting tool is planned with the following features:

a) A sensory feedback-based automatic cutting mechanism of the stalk at a certain distance (approx. 45 mm length) from the base of the mango. This will reduce the latex bleeding almost up to nil. Hence, latex stains and latex burns can be avoided and the self-life of the mango can be increased. The export quality also can be maintained.

b) Automating cutting ensures smooth harvesting operation without any unwanted jerks. This eliminates the chance of free fall of mango.
c) The cutting of the stalk with a length can eliminate the chance of sprinkling latex to the worker, hence, safe in operation.
d) After cutting, the mangoes will pass through a flexible hose to be collected at the packet at the ground. It facilitates continuous cutting and collecting operations without any interruption. It has another facility where operators don't have to carry any extra load while cutting the subsequent mango after cutting the previous one in a single shot.
e) An automatic grading system is included in the system to put the different graded mangoes into the respective packets without any human touch. It keeps the powder on the outer surface of the mango intact to maintain the export quality.
f) The telescopic stick facilitates adjustable harvesting length for different heights of trees.
g) Automatic cutting, collecting, sorting, and packing in a continuous manner in the system reduces overall harvesting time, manpower requirements, human efforts, complexity, and cost.
h) This is a semi-automatic harvesting tool, that can be operated by skilled labor is required, hence, user-friendly and economical.

MATERIALS AND METHODS

This advanced mango picking tool is designed for a continuous process of cutting, collecting, weighing, sending to the down, sorting, and putting the mango into the right packet for packing. From cutting of stalk of the mango to the remaining process up to putting the mango in the packet, will be done automatically without human touch. It consists of a cutting head assembly, a conveying path, and a sorting arrangement. The cutting head is placed on the top of a telescopic stick. The cutting head consists of two teethed cutting blades, a gear train, a DC motor, a jaw attachment for proper placement of mango into the cutter, and a mechanical switch (touch sensor) to trig the cutting operation. Just below the cutting area, a collecting aperture is attached along with a strain gauge sensor (load cell) for automatic weighing before entering the flexible conveying hose. The conveying hose is continued from the collection area near the cutting head to the packing zone at the ground level. At the end of conveying hose an automatic sorting arrangement is attached. The automatic sorting facility of mango works through a swiveling arm based on the weight input received from the strain gauge sensor. The swiveling arm comprises a stepper motor and a position sensor (potentiometer). Upon placing the cutting jaw (attached at the cutting head of a handheld telescopic stick) at the right position behind the mango by the operator, the mango will touch the mechanical sensor and activate the motor. The circular cutters are attached to the motor through a set of gear trains. When the motor will rotate, the cutting blade will also rotate to cut the mango stalk at a certain length. Here, the system is designed with a stalk cutting length of 45 mm. The cutting length of the mango stalk will be maintained by offsetting the cutting jaw from the cutter. After each cut, the motor will stop automatically and reactivate when it will come in contact with another mango. To avoid false rotating of the cutter in contact with mango leaf, the touch sensor has been designed with a certain pressure to activate. This automatic cutting can save the power consumption of the cutter. Then the mango will fall on the narrow opening of the collecting aperture and pass through the hose. When the mango will pass the narrow opening, the weight information will be received from the attached weight sensor (strain gauge). Based on the weight information, the swiveling arm (placed above a trolley where packaging boxes are placed) will slide to the right box before reaching the mango at the bottom. In the meantime, the mango will come to the bottom end of the hose and will be placed in the respective box without human touch. The automatic sorting system is integrated by a microcontroller board, as shown in Fig. 4(a), placed at the control panel above the trolley.

All the electronics components like the DC motor, stepper motor, sensors, and microcontroller are powered from a DC power source which is also placed beside the control panel above the trolley. The signals from the load cell and position sensor will be collected at the microcontroller board from different sensors, de-noised and control will be done through the stepper motor as shown in Fig. 4(b).

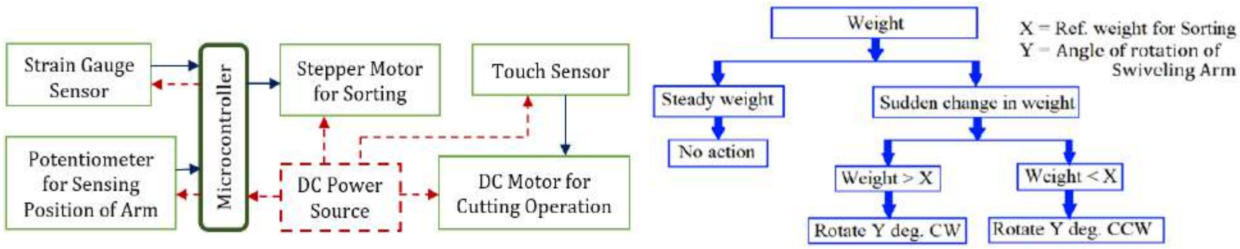

Figure 4: (a) Schematic diagram of the components, and (b) Algorithm for the automatic sorting process

DEVELOPMENT OF PROTOTYPE

The design considerations aim to make a low-cost handheld semi-automatic picker lightweight, easy to operate and to overcome the limitations of existing pickers basically for small and medium-scale farming. Hence, an effort has been made to modify the handheld pickers with nominal complexity in control. The entire process has been simulated in the CAD environment, as shown in Fig. 5, for validation.

Figure 5: Proposed harvesting operation in the simulation platform

An aluminum-made telescopic pole (stick) of 6 m has been selected for its lightweight and durability. The pole has 5 sub-sections for height adjustment for the small to moderate height of the tree. The cutter head, collecting aperture, and flexible hose guide are fixed with the telescopic pole. The cutting head assembly consists of two stainless steel teethed cutting blades, three nylon gears, a DC motor, a jaw, a mild steel frame, and a mechanical switch, as shown in Fig. 6, the nylon gears are used to reduce the weight at the head of pickers. Stainless steel teethed cutting blades are used as cutters. Two cutters are attached with two parallel shafts and the overlap of the cutters is 15 mm. The details of the mechanical components of the cutting head assembly are:

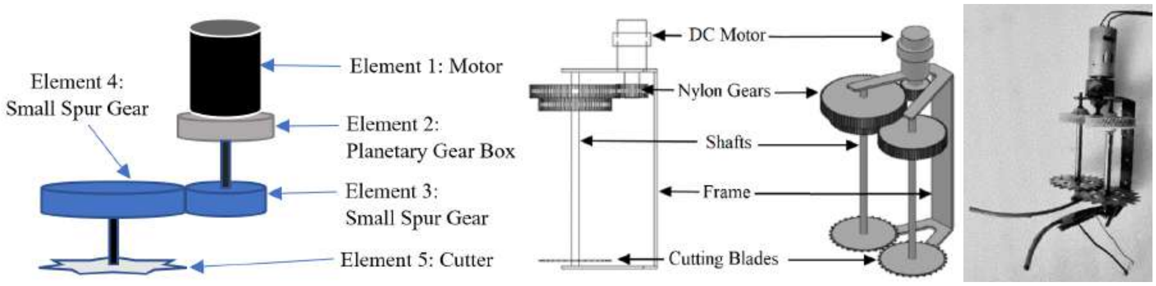

Figure 6: Cutting Head (a) Schematic (single cutter view), (b) General arrangement, and (c) fabricated

- *No. of teeth on each cutter* ***= 20***
- *Cutter dia,* $\boldsymbol{d_5 = 65}$ ***mm***
- *Large spur gear dia,* $\boldsymbol{d_4 = 52}$ ***mm***
- *Small spur gear dia,* $\boldsymbol{d_3 = 26}$ ***mm***
- *Rotation of motor,* $\boldsymbol{n_1 = 3{,}500}$ ***rpm*** *(at the loaded condition)*

Hence, the rotation of the small spur gear can be found, $\boldsymbol{n_3 = n_1 \times GB_m = 184}$ ***rpm***

($\boldsymbol{GB_m}$ *= Motor gearbox gear ratio* ***= 19****, taken from the datasheet)*

And, the rotation of stalk cutter, $\boldsymbol{n_5 = n_4 = n_3 \times d_3/d_4 = 92}$ ***rpm***

Accordingly, the motor torque can be taken, $\boldsymbol{T_1 = 0.561}$ ***N-m*** *(from the data sheet of the DC motor)*

Then, the torque on the small spur gear can be calculated, $\boldsymbol{T_3 = T_1 \times GB_m = 1.06}$ ***N-m***

Therefore, cutting torque of stalk, $\boldsymbol{T_5 = T_4 = T_3 \times GR = 2.12}$ ***N-m***

($\boldsymbol{GR}$ *= Gear ration of spur gears =* $\boldsymbol{d_4/d_3 = 2}$*)*

A 12V DC motor has been chosen for cutting operation. ATmega328P (Arduino Uno) microcontroller board is selected for controlling the automatic sorting mechanism. A 4.2 kg-cm 1.2A Stepper Motor and 12V, L293d motor driver has been assigned for moving the swiveling arm of the sorting mechanism. For powering the entire system, a 12V 12Ah Lithium-Ion battery is used. The connectivity diagram of the sorting operation is shown in Fig. 7(a). Finally, the prototype has been developed, as shown in Fig. 7(b), and subsequently, the second prototype, as shown in Fig. 7(c), has also been developed with a small modification in mechanical design.

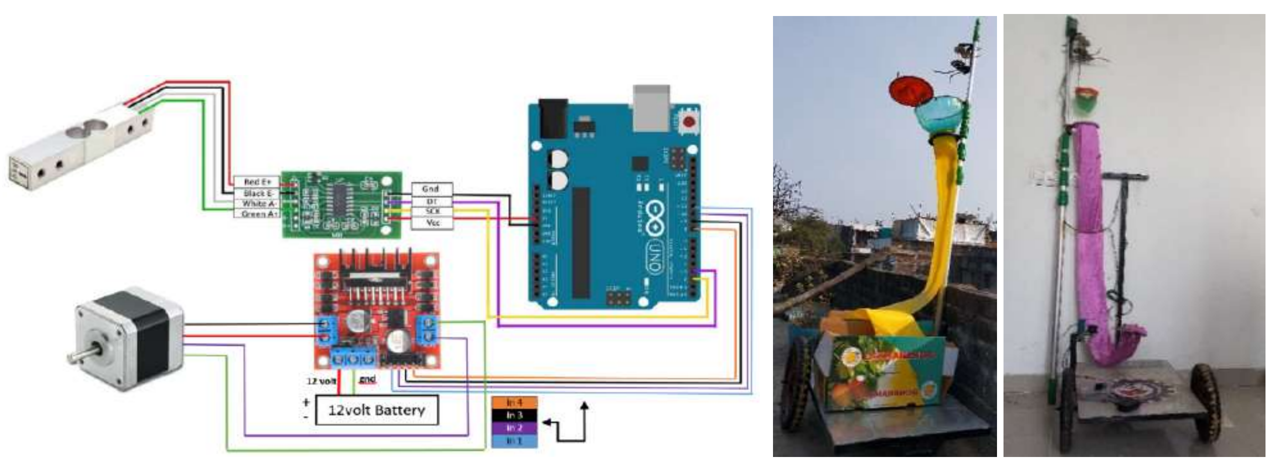

Figure 7: (a) Connectivity diagram of sorting operation, (b) Developed Prototype 1, and (c) Final Prototype

RESULTS AND DISCUSSION

The performance of the developed mango pickers has been evaluated with the following suggested parameters (Mohamed, 2017; Sabale et al., 2017):

i. **Cutting efficiency with respect to correct cutting length of Stalks (η_c):** This is the number of correct cut stalks that will be considered with a length more than or equal to 45 mm. Any stalk with a length of less than 45 mm will be considered undercut (***N_{uc}***).

   Therefore, $\boldsymbol{\eta_c} = \frac{N_h - N_{uc}}{N_h} \times 100 \quad \%$ where ***N_h*** is the total no. of Mangos Harvested

ii. **Sorting efficiency (η_s):** It will be calculated based on the number of incorrectly sorted mangoes (***N_{is}***). $\boldsymbol{\eta_s} = \frac{N_h - N_{is}}{N_h} \times 100 \quad \%$

iii. **Percentage of mangoes with mechanical damage during cutting operation ($\%_d$):** Any mechanical damage to fruit during cutting operation will be considered as harvesting loss (***N_d***). $\%_{\mathbf{d}} = \frac{N_d}{N_h} \times 100 \quad \%$

iv. **Percentage of mangoes with latex stain ($\%_{ls}$):** The number of mangoes with a considerable amount of latex stain (***N_{ls}***) will also be considered to main tail the export quality. Hence,

   $\%_{\mathbf{ls}} = \frac{N_{ls}}{N_h} \times 100 \quad \%$

v. **Percentage of free fall ($\%_{ff}$):** The number of free-falling mango (***N_{ff}***) from another branch during the cutting operation will also be considered as harvesting loss. Hence, this needs to be considered under the efficiency of the pickers.

   $\%_{\mathbf{ff}} = \frac{N_{ff}}{N_h + N_{ff}} \times 100 \quad \%$

vi. **Harvesting rate (*P_h*):** This is the number of mangoes harvested per unit of time.

   $$\boldsymbol{P_h} = \frac{N_h}{t} \quad {}^{Fruits}/_{Min.}$$

Trials have been conducted with the mango trees (Amrapali) of medium height (4 m to 5 m), as shown in Fig. 8. The trials have been carried out with the developed picker (DP) in parallel with the traditional pickers (TP) for performance comparison. From the trials, different harvesting data has been recorded as shown in Table 1.

Figure 8: Harvesting using the developed advanced picker

Table 1: Harvesting data of proposed picker and traditional handheld picker

Sl. No. of trials (I)	No. of Mangos Harvested, (N_h)		Time (in sec.), t		Number of undercut stalks, (N_{uc})		No. of mangos with mechanical damage, (N_d)		No. of incorrectly sorted mangoes, (N_{is})		Number of free-fall mangoes, (N_{ff})		No. of mangoes with latex stain, (N_{ls})	
	DP	TP	DP	TP	DP	TP	DP	TP	DP	TP	DP	TP	DP	TP
1	50	50	259	201	0	47	0	0	0	NA	0	3	0	19
2	50	50	264	196	0	48	0	1	1	NA	0	4	0	16
3	50	50	230	187	0	46	1	0	3	NA	0	6	0	16
4	50	50	245	209	0	42	0	0	1	NA	0	3	0	19
5	50	50	228	199	0	45	1	0	2	NA	1	4	0	13

The above data show that the number of undercut fruit stalks is zero as the possibility of undercut has already been eliminated by keeping the cutting jaw fixed 25 mm apart from the cutting blades. In this way, it has been prevented. The parametric performance of developed pickers and traditional pickers has been shown by the plots, as shown in Fig. 9.

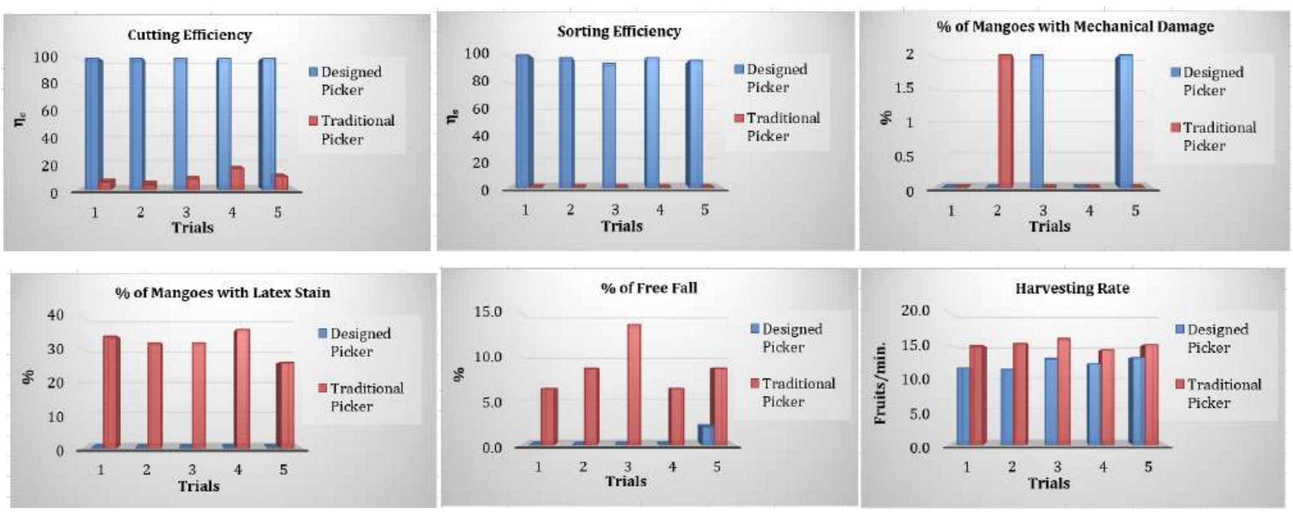

Figure 9: The parametric performance of developed pickers and traditional pickers

From the above performance assessment, it has been seen that the developed pickers are cable to eliminate latex stain problems and free fall losses. With the satisfactory cutting efficiency, sorting efficiency, and harvesting rate including a number of additional features, this advanced mango picker stick can be a good alternative to traditional pickers for medium to small-scale farmers to improve the entire harvesting process.

CONCLUSION

The advanced mango picker is a low-cost, user-friendly handheld mango picking tool with a trolley-mounted sorting arrangement that eliminates latex stain, and latex burn and reduces harvesting losses due to fruit fall and human hazards. The design includes a sensory feedback-based automatic cutting mechanism of the stalk at a certain distance from the base of the mango and an automatic sorting facility of mango based on their size. Conformity on automatic cutting at the right position of the stalk can decrease latex bleeding and prevent free fall. An automatic sorting mechanism will sort the mangoes in grade based on demand. The device has been designed for a continuous process of cutting, collecting, weighing, sending them down, sorting, and putting them into the right packet for packing. The worker needs to hold the cutting head (attached at the top of a handheld handle) behind the mango and the remaining process up to putting in the packet will be done automatically without human touch. It can reduce the overall harvesting time and effort which can be used by semiskilled people too. Accordingly, a performance assessment has been done and it has shown that the developed pickers are cable to eliminate latex stain problems and free fall losses with satisfactory cutting efficiency, sorting efficiency, and harvesting rate and it can be a good alternative to traditional pickers for medium to small-scale farmers to improve the entire harvesting process. As a future scope, a vision-capturing system with a display can also be integrated with the system to monitor the cutting operation more clearly.

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