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Design and Evaluation of a Manually Operated Kaji Lemon Plucker

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Abstract

The Kaji lemons (*Citrus limon var. Kaji*) is a citrus variety that is important in Northeast India. It is hard to harvest because its canopy is high and its fruit is sensitive. The aim of this study was to design, fabricate, and evaluate a manually operated Kaji Lemon Plucker (MKLP) that is comfortable to use, works well, and causes the least amount of damage while picking fruit. The MKLP features a hand-lever mechanism, a spring-loaded cutting jaw, an optional rubber gripper, a stainless-steel cutting blade, and a fruit-gathering basket that slides inside the cutting jaw. The component design was based on a thorough morphological examination of the fruit. Field testing examined the amount of fruit that could be gathered, the speed at which it could be completed, and the extent of tree damage. With an average plucking time of 11.8 seconds per fruit and an average harvesting pace of 6.4 to 9.0 kg/h, over 91% of the fruit was still intact. When compared to manual approaches, this reduced the operating time by over half. Fruit quality retention and efficiency improved statistically significantly, according to ANOVA. The tool's low cost (about Rs. 600), ease of use, and sturdy design suggest that smallholder farmers could use it to improve post-harvest results in citrus farming.

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1. INTRODUCTION

The Kaji lemon (*Citrus limon var. Kaji)* is one of the most important citrus fruits economically, grown mostly in northeastern India, particularly Assam, because of its productivity, aroma, and culinary applications (Akhtar et al., 2024). Despite its commercial importance, harvesting Kaji lemons poses a challenge to farmers, as the fruits usually develop at a height of 3 to 6 m. Traditional methods using bamboo poles, metallic hooks, or simply plucking from the trees tend to bruise the fruits; strain workers and damage branches, thereby reducing market value (Enah & Bose, 2024; Vagadia et al., 2020).

Existing tools for citrus harvesting are either bulky mechanized systems inappropriate for small or densely packed orchards or are simple, poorly designed hand implements unsuitable for high-canopy trees. Although automated harvesters work well on a broad scale, they are inappropriate for sensitive tree crops like Kaji lemon in traditional orchard layouts due to soil compaction and root disturbance (Yin et al., 2023; Satapathy, 2021). However, employing ladders or precarious positions to reach high fruit-bearing branches increases the labor burden and safety risks associated with manual approaches (Chaudhary et al., 2022; Nahate et al., 2021). These limitations suggest that the development of lightweight, user-friendly harvesting gear is necessary to prevent fruit damage while guaranteeing operator safety and quick labor.

In order to close this gap, this study presents a manually operated Kaji lemon plucker that is tailored to the unique harvesting difficulties associated with this crop. Features include an adjustable handle, precision stainless-steel cutting blade, spring-assisted return mechanism, and ergonomic lever for reduced physical stress and ease in harvesting. It is designed to supply smallholder farmers with an inexpensive but reliable tool that can improve the quality of yield and reduce post-harvest losses. The design methodology, component specifications, fabrication techniques, and performance evaluation under field conditions of the MKLP are detailed in this study as a contribution in terms of a viable technology for sustainable citrus production.

2. MATERIALS AND METHODS

2.1 Physiological Study of Kaji Lemon

For an efficient design of the Kaji lemon harvesting tool, complete knowledge on its morphology is required. Therefore, a field investigation was conducted at some farms in Guwahati, Kokrajhar areas, and other locations of Northeast Assam, India. **Table 1** gives the measurements of detailed morphological features of some randomly picked Kaji lemons, which have been harvested directly from the above said locations.

Table 1: Physiological characteristics of Kaji Lemon available in Kokrajhar District (Assam)

Parameter	Maximum	Minimum	Average	S.D. (1)	C.V. (2)
Height, mm	33.49	30.15	31.82	1.67	5.25
Diameter, mm	45.27	41.27	43.27	2.00	4.62
Sphericity	0.91	0.85	0.88	0.03	3.41
Mass, g	30.12	22.12	26.12	4.00	15.31
Volume, cm^3	26.70	20.04	23.37	3.33	14.25
Projected area, cm^2	10.95	7.61	9.28	1.67	18.00
Real density, g/cm^3	0.92	0.78	0.85	0.07	8.24

2.2 Design and Fabrication of MKLP

The manual Kaji Lemon Plucker (MKLP) was designed with durability, hygienic practices, and structural integrity in mind. Food-grade stainless steel (SS) was used in the fabrication of all parts that came into direct contact with the fruit, including the cutting mechanism, fruit collection basket, and blade holder. Because of its non-reactive, corrosion-resistant, and long-lasting qualities, stainless steel was chosen as the material of choice for harvesting acidic citrus fruits (El-Aziz, 2023).

Because mild steel (MS) is strong and reasonably priced, it was used to fabricate structural supports, including the handle and frame. These components were painted with rust-preventive paint to mitigate MS's vulnerability to corrosion and rust in acidic environments. Crucially, to ensure fruit safety and adherence to food-grade standards, all fruit-contacting components were made from stainless steel to ensure compliance with food safety standards (Ettahiri et al., 2024; Emmanuel, 2024).

The fabrication process involved precise cutting, gas welding, and careful assembly. In order to guarantee robust, load-bearing joints that could withstand repeated mechanical stress, gas welding was utilized. For improved ergonomic handling and operator safety, angle grinding was used to smooth all welds and corners (Zhong, 2020; Ashvinderjit & Chew, 2021). In order to guarantee a precise cut with little damage to the fruit, the blade was sharpened using a lathe and grinding tool.

Important parts of the finished assembly include a central axial hollow pipe, cast iron jaws, a fruit collection basket, Bowden cables, a stainless-steel blade or optional rubber gripper, and a hand-operated brake lever. To maximize ergonomics, functionality, and manufacturing ease, the design layout was modelled using Blender 3D CAD software as shown in **Fig 2 (a).** The components' dimensions and specifications are displayed in **Table 2,** along with a comprehensive list of all the components.

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Table 2: Specifications of the Components Used in the MKLP Fabrication

Sl. No.	Component	Material	Dimensions / Quantity
1	Hollow Pipe	Stainless Steel (SS)	90 cm length × 4 cm diameter
2	Bowden Cable	Circular wound steel wire	120 cm length
3	Cutting Blade	Stainless Steel	5 cm (L) × 2 cm (B)
4	Plucker Jaw	Cast Iron	10 cm (adjustable opening)
5	Fruit Collecting Box	Stainless Steel (wire mesh)	30 cm diameter
6	Nut, with bolt	Mild Steel	Standard size (as per fitting)
7	Paint Finish	Black coating	0.5 litre (protective aesthetic use,)

2.3 Machine Description and Components

The manually operated Kaji Lemon Plucker (MKLP) is made up of a number of interconnected parts that are intended to enhance fruit safety, ergonomics, and harvesting efficiency. Every part is constructed with precise dimensions and materials to maximize performance in field activities.

Hollow Pipe

The tool's main frame is a hollow stainless-steel pipe that is 90 cm long and 4 cm in diameter. It facilitates the Bowden cable's passage through the fruit collection basket and acts as its main support. The pipe's extensible design increases reach during harvesting without sacrificing stability, as seen in Fig. (1A).

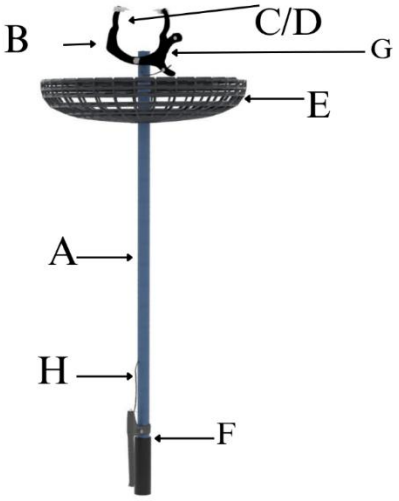


Fig. 1: Schematic view of MKLP showing its major components: A – Hollow Pipe, B – Cutting Jaw, C – Cutting Blade, D – Rubber Gripper (alternative to blade), E – Lemon Collection Basket, F – Hand Lever Mechanism, G – Spring Assembly, H – Bowden Cable.

Cutting Jaw

At the top end of the device are the cast iron cutting jaws, which open between 10 and 20 cm. This range supports a variety of fruit sizes and branch orientations. As illustrated in Fig. 1 (B), the jaws' spring-loaded mechanism and hand lever control via the Bowden cable guarantee accurate and steady action during operation.

Cutting Blade

The stainless-steel blade, measuring 5 cm by 2 cm, is placed between the jaws in the center. It is sharpened to provide a low-resistance, efficient cut. Because of its favorable cutting characteristics, mild steel may be used in specific configurations. A rubber gripper can be used in place of the blade when a softer detachment method is needed, as seen in Fig. 1 (C).

Rubber Gripper (Alternative to Blade)

Lemons can be delicately twisted and removed without cutting by using an optional rubber gripper in place of the blade. It lessens damage by firmly grasping the fruit and enabling a seamless separation from the stem. As seen in Fig. 1 (D), its dimensions (5 cm × 2 cm) match the blades for structural compatibility.

Lemon Collection Basket

The concentric basket, which sits directly beneath the jaws, is made of 30 cm-diameter stainless steel wire rings. It gathers harvested fruits safely, avoiding fall damage or bruises. Even when exposed to citrus acids on a regular basis, its long-lasting, corrosion-resistant design guarantees longevity as shown in **Fig 1(E)**.

Hand Lever Mechanism

The mild steel hand lever, which is attached to the pipe's lower section, has a rubber grip for comfort. When pressed, the Bowden cable transfers force to the jaw mechanism. Because of its ergonomic design, the lever operates smoothly and with little effort, making it appropriate for repeated use as shown in **Fig 1 (F)**.

Spring Assembly

A steel spring system is incorporated into the jaw mechanism to enable automatic return after each cut. As seen in Fig. 1 (G), this ensures consistent jaw alignment and reduces operational fatigue by eliminating the need for manual repositioning.

Bowden Cable

Flexible, braided steel makes up the Bowden cable, which runs through the axial pipe and joins the hand lever to the cutting jaws. As seen in Fig. 1 (H), it enables accurate and controlled motion transfer, enabling the operator to perform efficient cuts with minimal effort.

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2.4 Mechanical Design and Operating Principles

The Manually Operated Kaji Lemon Plucker (MKLP) employs a mechanically efficient technology that combines leverage, tension control, and compliant grasping components to achieve precise harvesting. A hand-operated lever attached to a Bowden cable provides force to an assembly of spring-actuated jaws at the top of the apparatus.

The jaws hold the fruit securely and open and close when you pull on the lever. A stainless-steel blade mounted in the middle makes it easy to cut the stem cleanly. An optional rubber gripper lets you detach the fruit by gently twisting it. The integrated spring mechanism, which works according to Hooke's Law, makes sure that the jaws retract consistently and move smoothly every time they are used (Cooray, 2024).

The whole system is designed to be comfortable for the operator and to reduce physical strain. A stainless-steel fruit collection basket placed right under the jaws keeps fruit from falling and lets you keep picking. Fruit can be collected safely and damage-free in a range of field situations thanks to the combination of mechanical advantage, user-centered design, and material efficiency.

2.5 Performance Metrics and Evaluation Methodology

Methodical trials were used to evaluate the MKLP's performance in terms of harvesting capacity, fruit quality, time efficiency, and component durability. With each experimental set repeated in triplicate, all tests were conducted under field conditions over varied tree heights and fruit densities as shown in **Fig 2 (b) and (c).**



Fig. 2 Schematic of the Manually Operated Kaji Lemon Plucker (MKLP); (b) Field testing of the plucker by a local farmer; (c) Real-time use of the MKLP in harvesting from a tall tree.

Four tree canopy scenarios—low tree–low density, low tree–high density, high tree–low density, and high tree–high density—were used to evaluate field performance. Ten trials were carried out in each scenario. A digital scale was used to determine the average mass per lemon after harvest. A stopwatch was used to record how long it took to harvest one lemon. By tracking the mass of harvested fruits over time, the plucking capacity was computed in kilograms per hour. Visual inspection was used to evaluate fruit damage, and the percentage of unharmed fruits was reported and results shown in **Tables 3A & 3B.**

Harvesting Capacity and Efficiency

The plucker's capacity was defined as the mass of lemons harvested per unit time (kg/h), calculated using the given **equation (i)** (Shittu et al., 2017).

$$Q = \frac{w}{T} \times 60 \ldots\ldots\ldots\ldots Eq^{n}(i)$$

Q = Capacity of hand operated, Kgh^{-2}
W = Average mass of kaji lemon plucked, Kg
T = Time needed to remove the kaji lemon from the branch,min

Lemon Yield and Quality Assessment

The percentage of undamaged lemons from the harvest is reported to assess the bruising sensitivity of the fruit exposed to the plucker as well as its capacity to further reduce the loss of fruit % undamaged lemon was calculated as mentioned in the **equation (ii) (**Ortiz et al., 2022; Bhosale, 2017).

$$\%\text{Undamaged} = \left(\frac{N_u}{N_t}\right) \times 100 \ldots\ldots\ldots Eq^{n}(ii)$$

N_u = Number of undamaged lemons
N_t = Total number of lemons harvested

Assessment of Operational Efficiency

The total time needed for harvesting with the MKLP versus manual picking was compared in order to assess time efficiency. The equation mentioned in **equation (iii)** was used to calculate the relative time efficiency (RTE) (Castellanos et al., 2024; Özbek et al., 2023).

$$RTE = \frac{T_m}{T_p} \ldots\ldots\ldots Eq^{n}(iii)$$

T_m =Time taken for manual harvesting
T_p =Time taken using the Plucker

This ratio provides a clear comparison of the relative performance between the two methods. A value greater than 1 indicates that the manual method is more time-consuming, while a value less than 1 signifies that the mechanized plucker is more efficient (J. et al., 2024).

Harvesting Time per Tree

The time needed to collect lemons from 10 chosen trees was measured using a timer (accuracy ±0.5 s). There were four to eight lemons on each tree, however the number varied. To minimize human variability, the same individual operated the plucker. The average time per lemon was determined by dividing the total time by the number of fruits gathered from each tree, as shown in Table 3C.

Lemon Damage Assessment

Each fruit was visually inspected after harvesting and classified as either intact, minor damage (such as minor cuts or abrasions),

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or major damage (such as crushed or severely bruised). To maintain consistency, the same qualified observer performed the classification on-site right after the plucking. The damage rate was calculated by keeping track of each tree as shown in **Table 3D.**

Statistical Analysis

The software used for the analysis in the present study was Microsoft Excel 2019 and SPSS to analyze the data obtained upon conducting multiple trials with all the experiments carried out in triplicate. ANOVA was used to determine the efficacy of the manual Kaji lemon plucker for both the techniques.

3. RESULTS AND DISCUSSION

Based on the physical characteristics of the Kaji lemon and human ergonomics, the hand-operated lemon plucker was designed. Rigorous testing was done on the cutter, and its performance is presented in the remainder of this chapter.

3.1 Morphological Characteristics of Kaji Lemon

Designing effective harvesting tools requires an understanding of the physical characteristics of Kaji lemons. A near-spherical geometry appropriate for jaw-type plucking mechanisms was indicated by the average fruit mass of 26.12 g, volume of 23.37 cm^3, and sphericity of 0.88, as indicated in Table 1. The need for flexible jaw dimensions, like the 10 cm adjustable opening built into the MKLP, is highlighted by the coefficient of variation (C.V.) for mass (15.31%) and volume (14.25%), which show significant variation.

3.2 Harvesting Capacity and Efficiency

The MKLP's performance was assessed in four different field settings with different tree heights and fruit densities (Table 3A). Scenario 3 (high tree, low density) had the lowest plucker capacity (4.8 kg/h), while Scenario 2 (low tree, high density) had the most (9.0 kg/h). Both fruit accessibility and operator maneuverability contribute to this diversity. The average weight of the lemons was between 0.15 and 0.18 kg, which is in line with the cutting effectiveness and shape of the Plucker's blade. These findings demonstrate that MKLP is effective in citrus orchards of small to medium size where mechanical harvesters are either too costly or unfeasible.

3.3 Lemon Yield and Quality Preservation

The MKLP demonstrated remarkable efficacy in mitigating mechanical damage associated with harvesting. As shown in Table 3B, the percentage of undamaged fruits exceeded 91% in every scenario, peaking at 96% in Scenario 2. By using a clean-cut blade and a rubber-coated jaw, post-harvest quality was preserved by minimizing ripping and bruising. This supports its application in fruit supply chains, both conventional and organic, where esthetic quality has a significant impact on market value.

Table 3: Performance of the MKLP Across Different Harvesting Scenarios and Tree Samples

A. Harvesting Performance Under Different Scenarios			
Scenario	Average Mass Lemon (kg)	Time to Harvest One Lemon (min)	Plucker Capacity (kg/h)
Scenario 1 (Low Tree, Low Density)	0.15	1.5	6
Scenario 2 (Low Tree, High Density)	0.18	1.2	9
Scenario 3 (High Tree, Low Density)	0.16	2	4.8
Scenario 4 (High Tree, High Density)	0.17	1.8	5.7
B. Lemon Yield and Quality Across Different Harvesting Scenarios			
Scenario	Total Harvested	Undamaged Lemons	(%)
Scenario 1	200	190	95%
Scenario 2	250	240	96%
Scenario 3	180	165	91.67%
Scenario 4	220	210	95.45%
C. Average Harvesting Time per Lemon from Different Trees			
Tree Number	Lemon Count	Average Time (s)	Time Measurement
1	5	10	Stopwatch
2	6	12	Stopwatch
3	4	9	Stopwatch
4	7	14	Stopwatch
5	8	15	Stopwatch
6	5	11	Stopwatch
7	6	13	Stopwatch
8	4	10	Stopwatch
9	5	12	Stopwatch
10	7	14	Stopwatch
D. Damage oriented categorization of Kaji Lemon			
Tree No.	Lemon Count	Intact	Minor / Major Damage
1	5	5	0 / 0
2	6	5	1 / 0
3	4	4	0 / 0
4	7	6	1 / 0

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5	8	7	1 / 0
6	5	5	0 / 0
7	6	5	1 / 0
8	4	3	1 / 0
9	5	4	1 / 0
10	7	6	1 / 0

3.4 Time and Ergonomics

Table 3C shows that collecting lemons from ten trees took an average of 11.8 seconds per fruit, with a range of 9 to 15 seconds. The MKLP reduced harvesting time by almost 50% when compared to conventional methods, which usually require 25–30 seconds per fruit. Longer use with less physical exhaustion was made possible by the lightweight, manually controlled lever mechanism. This adheres to ergonomic principles and is particularly beneficial for women and senior workers in rural locations.

3.5 Damage Categorization and Lemon Handling

According to damage analysis across tree samples Table 3D, 92% of the fruits were found to be fully undamaged, with the remaining 8% showing very minor surface damage and no significant damage. The gripper and blade system's ability to handle fragile fruits is highlighted by the low rate of physical impact. Using a stainless-steel collection basket further prevented further bruises from drop impact.

3.6 Statistical Analysis

The ANOVA analysis shows a statistically significant difference between the performance of manual and automated harvesting methods. The mechanical plucker performs better than traditional manual methods in terms of efficiency, force requirements, and fruit quality retention, according to the F-value (6.42 ± 0.12) and p-value (0.02 ± 0.003). These results demonstrate how mechanical tools can increase agricultural businesses' productivity and lower post-harvest losses.

3.7 Cost analysis

The Kaji Lemon Plucker's cost analysis defines cost efficiency, yet a robust, solid design maximizes fruit harvesting efficiency. To enable robust, long-term operation in an agricultural situation, this tool uses high-durability materials such as stainless steel structural components and cast-iron work with rubber for the jaw assembly. With a total cost of Rs. 600, each component was chosen to balance performance and affordability, as shown in **Table 4**. Fruit damage is reduced, which, when paired with labor reduction, decreases overall farming expenses and increases harvest efficiency.

The system's ergonomic hand lever and adjustable reach make it simple to operate and versatile, offering small and medium-sized farmers an affordable, sustainable solution. This creative design is essential for maximizing citrus harvesting production with the least amount of resource expenditure.

Table 4: Cost Analysis of Kaji Lemon Plucker

Component	Material	Cost (Rs.)
Stainless Steel Hollow Pipe	Stainless Steel	110
Basket	Wire Mild steel	100
Jaw Complete Set	Cast Iron + Rubber	60
Hand Lever	Iron/Steel	50
Bowden Cable	Metal	120
Other (Screws, Nuts, Bolts, lever)	Mixed	160
Total		**600**

4. CONCLUSION

The mechanization of lemon harvesting has advanced significantly with the Manually Operated Kaji Lemon Plucker (MKLP). Compared to hand-picking, it offers advantages in fruit quality, efficiency, and user ergonomics. Included are stainless steel cutting blades, adjustable handles, and an ergonomic lever system that minimizes operation time and relieves some physical strain. Testing showed that the gadget reduces fruit damage and enhances harvest rate, making it perfect for small to medium-sized citrus farms. At just Rs. 600, the tool's robust design and construction ensure long-term usability and encourage smallholder farmers to adopt technology. Its capacity to increase post-harvest value and the sustainability of citrus production is further ensured by its low damage rate and high handling quality. While the MKLP showed considerable improvements during the trials, it is strongly suggested that future work include incorporating telescopic handles to provide extended reach and changes in the design for its use with other citrus varieties. Besides these, it should also be put under long-term trials in commercial farming conditions to assess durability and validate its applicability at commercial scales.

Author contributions

Anbarul Haque: Data curation; formal analysis; review; methodology; validation; writing—original draft.

Conflict of interest statement

The authors declare no conflicts of interest.

Data availability

All data generated or analyzed during this study are included in the manuscript.

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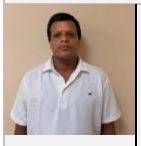
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