Journal of Applied Horticulture, 27(1): 20-23, 2025
https://doi.org/10.37855/jah.2025.v27i01.04
Journal of Applied Horticulture
ISSN: 0972-1045

Performance evaluation of tractor-mounted hydraulic operated ladder for coconut and mango

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Abstract

The high labor requirements and inherent risk of traditional harvesting and pruning of tall trees like coconut and mango make them difficult to harvest and prune. Mechanized machines do exist, but they are too heavy, too expensive, and unsuitable for Indian marginal farmers with small landholdings, which reduces productivity, efficiency, and worker safety. A tractor-mounted hydraulic ladder was evaluated for harvesting coconut and mango under field conditions to address these challenges. The ladder can rotate 360 degrees and covers up to four trees with simple directional control. Trees up to 12 meters tall can be harvested, pruned, and sprayed. Harvesting efficiencies of 75-81% for coconut and 76-80% for mango were recorded in field evaluations. Operational costs for coconut are Rs. 439 per hour and Rs. 530 per h for mango, and the ladder can harvest 7-9 coconut trees per hour. This system offers a feasible, low-cost solution for small and marginal farmers who struggle with the use of traditional and expensive machinery.

Key words: Hydraulic ladder, coconut harvesting, orchard, spraying, hydraulic motor

Introduction

Most fruits from tall trees in India are harvested manually by skilled tree climbers. Yet, fruit growers in developing countries face two critical challenges that could threaten their businesses. First, the labor available for fruit harvesting is in steady decline as workers move from agriculture to higher paying jobs in construction and industry. Second, the cost of manual labor is increasing each year, and it becomes increasingly important to improve labor productivity to maintain or lower costs. Moreover, traditional methods of fruit harvesting are prone to damage, thereby reducing market value, increasing post harvest losses and increasing risks to consumer health and satisfaction. Buyers often down grade or reject damaged fruits, which in turn lowers the price for farmers and increases food waste.

Harvesting, pollination and pruning are especially labor intensive and together they make up more than 80 percent of production costs in some of the crops. For example, both traditional and mechanical methods are used in various cultural operations in coconut and mango orchards. The most difficult part of these operations though, is being able to access the tree crown, as the trees can reach as high as 12 meters in height, which presents a major risk to workers, especially in pruning and harvesting operations where the risk of falling is very real. According to Al-Kiady (2000), date palm cultivation requires specialized labour which is both scarce and expensive, thus hindering date production. Comprehensive physical and mechanical data for date palms is needed for research into mechanization in this sector. Various studies indicate that mechanized cultural operations, whereby the tree can stand some stress, could revolutionize date palm cultivation (Ismail and Al-Gaadi, 2006; Mazloumzadeh *et al.*, 2008).

The tractor mounted hydraulic elevator developed by Kolhe *et al.* (2011) was designed for harvesting and pruning of mango orchards up to 12 meters tall, while using available tools to maintain machine stability. The system was able to harvest 5,400 Alphonso mangoes (1,400 kg) per day at a rate of 0.08 h−1, and had a field capacity of 5,400 Alphonso mangoes (1,400 kg) per day. In a similar vein, Kleine and Karkee (2015) developed a semi-automated mechanical apple harvesting system with a unique dual motor actuator (DMA). The purpose of this system was to decrease labor costs and increase efficiency, with an average removal efficiency of 35% across fruiting limbs, 88% in the actuation zone. Minimal damage to the fruit (10%) and the lowest bruise rate (4%) were achieved with the DMA's circular pattern and 200 cycles per minute rhythm. Thiyagarajan and Tajuddin (2018) also developed a hydraulic operated ladder for mango orchard harvesting and pruning. Workers and tools up to 10 meters were lifted by this ladder, increasing productivity and decreasing costs. Deepak and Kishor (2016) also tested a hydraulic elevator system with a four cylinder stabilizing system that gave stability up to 12 meters with 120 kg in the bucket. When tested on different mango varieties in the orchard, the system harvested 58.84 kg per hour of average harvest weight. These innovations together emphasize major steps in mechanization for orchard management, with the intention of increasing efficiency, and also safety of the workers.

Deogirikar *et al.* (2020) developed a lightweight, manual PVC sapota harvester that improves canopy penetration but restricts visibility because it is opaque material, resulting in neck and shoulder strain. Later, a 6 mm MS rod version was introduced, with a better visibility and a wider angle for a more efficient harvesting. According to Zhang *et al.* (2020), mechanical apple harvesting has advanced, and new technologies such as sensors and machine learning could be used to enhance harvest assist platforms, but economic benefits still need to be further analyzed. Nahate *et al.* (2021) compared traditional and improved citrus harvest methods, and found that the latter reduced fruit damage and musculoskeletal stress while increasing the harvest rate. Masum *et al.* (2023) designed a low cost mango picker to reduce latex stains and fruit losses during mango harvesting.

The aim of this study was to assess the performance and feasibility of a tractor mounted hydraulic ladder for harvesting, pruning and spraying coconut and mango trees under field conditions. The study evaluated the operational efficiency, cost effectiveness and safety of hydraulic ladder in comparison to traditional and heavy mechanized equipment especially for small and marginal farmers of India.

Materials and methods

Construction of tractor-mounted hydraulically operated ladder: The functional components of the developed tractor-mounted hydraulically operated ladder are trailer assembly, ladder assembly and hydraulic system.

It is a tractor-drawn two-wheel trailer developed with load-bearing capacity and weight distribution by considering the weight of the hydraulic ladder. The hydraulic ladder was bolted on the trailer platform frame. The hydraulic ladder unit can be rotated with the help of a turn table for 360 degrees by using a worm and worm-wheel gearbox with a ratio of 40:1. Entire hydraulic ladder unit is operated by the hydraulic system which consists of a type pump that is connected to the tractor PTO with the cardon shaft, hydraulic motor, hydraulic cylinders and direction control valves.

Vane-type pump (Fixed displacement and Balanced): Pumping action in a vane-type pump is caused when the vanes are allowed to track along a cam ring. In a balanced design vane pump a circular rotor with vane slots is concentrically positioned with the axis of an elliptical cam ring. The selected van-type pump has a flow capacity of 45 lpm and a maximum operating pressure is around 175 bar to withstand various operating pressures and temperatures of the hydraulic ladder

Hydraulic gerotor motor: A hydraulic motor coupled with the gear box for rotation of complete assembly up to 360^0 on both the sides was used. In addition to the pump and motors, there were about six numbers of cylinders which was fixed to the hydraulic ladder unit for stabilizing & lifting the radial arms. The six-way directional control valve was used in the hydraulic ladder unit to control the operations like stabilizing, lifting and rotation by the operator itself during the field operations. The view of the tractor-mounted hydraulically operated ladder and specifications are shown in Fig. 1 and Table 1.

Fig. 1. View of the tractor-mounted hydraulically operated ladder

Table 1. Specifications of tractor-mounted hydraulically operated ladder

S. No.	Details	Value
Trailer assembly		
i	Trailer size, m	2.72 × 1.71 × 1.56
Hydraulic assembly		
i.	Gearbox size, m	0.35 × 0.35 × 0.32
ii	Gear ratio	40:1
iii	Type of hydraulic pump	Vane type pump
iv	Type of hydraulic motor	Gerotor
v	Cage size, m	0.75 × 0.75 × 1
vi	Directional valve	Six bank valves
vii	Rotation, degree	0 to 360
viii	Maximum cage load, kg	300
ix	Jacking width, m	4.5
x	Minimum height, m	4.0
xi	Overall dimensions, (L × B × H) m	6.0×3.5× 4.8
xii	Weight of the attachment (Including trailer), kg	880

The hydraulic ladder works like an implement and it can be easily hitched to a tractor at the time of work and unhitched when it is not required. The hydraulic ladder can be used for harvesting of coconut, fruits in any of orchard crops, pruning of trees, and spraying over the tree canopy up to a height of 12 m. The hydraulic ladder can be easily transported to different places with the help of a tractor. For conducting performance evaluation, the coconut and mango trees were randomly selected in the University farms and also in the nearby villages of Paiyur and the diameter of the coconut tree and height of the coconut and mango trees and their average readings were recorded.

Results and discussion

Performance evaluation of hydraulically operated ladder for orchard crops: The hydraulic ladder was a trailed type, hitched to a 33.5 kW tractor by a cardan shaft powered by the tractor's PTO. The shaft was connected to the tractor's PTO at one end, and the other end powered the hydraulic pump. Its total lifting height was 12 meters and the ladder could rotate 360 degrees in both clockwise and anticlockwise direction. The tractor mounted hydraulic ladder was used in three trials for harvesting operations in coconut and mango orchards at the University Research Station and a farmer's field. The tractor PTO was at 400 rpm, for efficient bucket lift and lowering. Ten fieldworkers, between 25 and 40 years old, and with an agricultural background, were selected and trained to operate the ladder. The ladder was operated by each worker at different vertical heights and rotation angles (0 to 180°). The hydraulic ladder was designed for ease of use by people with little or no experience with machinery handling.

Even on undulating terrain, transportation of the hydraulic ladder between fields was simple. Up to a height of 12 meters, the same machine could also be used to spray, tree prune and perform maintenance work. Figs. 2 and 3 showed the operational setup for the tractor mounted hydraulic ladder in coconut and mango orchards. Results from the coconut and mango harvesting trials are depicted in Tables 2 and 3, and Fig. 4.

Effect of total operating time vs height of coconut and mango tree: For this evaluation, the height and diameter of the coconut tree were taken from 8 to 10 m and 0.84 to 0.92 m, respectively. From Table 2, it was observed that the average setting up time,

Fig. 2. Operational view of coconut harvesting

Table 2. Field trials of the hydraulic ladder for coconut harvesting

Particulars	Trial 1	Trial 2	Trial 3	Mean	SD
Date of trial	04.10.24	18.04.24	19.06.24		
Location	RRS, Paiyur	RRS, Paiyur	Paiyur Village		
Trees harvested, Nos.	10	9	10	9.67	0.58
Ave. height of the tree, m	8	10	10	9.33	1.15
Ave. diameter of the tree, m	0.86	0.92	0.84	0.87	0.04
Ave. setting up time, s	22	29	25	25.33	3.51
Ave. time for lifting the bucket, s	20	23	21	21.33	1.53
Ave. time for lowering the bucket, s	16	16	14	15.33	1.15
Ave. time for rotation of the unit, s	16	14	18	16.00	2.00
Total time (excluding harvesting), s.tree^{-1}	74	82	78	78.00	4.00
Harvesting capacity, trees.h^{-1}	68	59	65	64.00	4.58
Harvesting efficiency, %	76	81	75	77.33	3.21

Table 3. Field trials of the hydraulic ladder for mango fruit harvesting

Particulars	Trial 1	Trial 2	Trial 3	Mean	SD
Date of trial	18.04.24	09.05.24	30.06.24		
Location	RRS, Paiyur	RRS, Paiyur	Jagatap		
Ave. height of the tree, m	6	7	9	7.33	1.53
Ave. setting up time, s	23	25	29	25.67	3.06
Ave. time for lifting the bucket, s	12	13	16	13.67	2.08
Ave. time for lowering the bucket, s	8	8	10	8.67	1.15
Ave. time for rotation of the bucket , s	18	20	23	20.33	2.52
Total time (excluding harvesting), s. tree^{-1}	61	66	78	68.33	8.74
Harvesting capacity, kg.h^{-1}	130	147	139	138.67	8.50
Harvesting efficiency, %	79	80	76	78.33	2.08

lifting the bucket, lowering the bucket and rotation of the unit are 22 to 29 s, 20 to 23 s, 14 to 16 s and 14 to 18 s, respectively. Whereas for height of the mango tree was taken from 6 to 9 m. From Table 3 it is observed that the average setting up time, lifting the bucket, lowering the bucket and rotation of the unit are 23 to 29 s, 12 to 16 s, 8 to 10 s and 18 to 23 s, respectively.

Fig. 3. Operational view of mango harvesting

Coconut and mango harvesting efficiency: Total time (excluding harvesting) required to operate the hydraulic ladder for coconut and mango trees is from 74 to 86 s.tree^{-1} and 61 to 82 s.tree^{-1}and the harvesting efficiency of the hydraulic ladder for coconut and mango was found to be 75 to 81 percent and 76 to 80 percent, respectively (Fig. 4).

Strong positive correlation existed between tree height and total time, meaning taller trees require more time to handle. The negative correlation between total time and harvesting capacity shows that as time spent per tree increases, fewer trees can be harvested per hour for coconut and mango. Harvesting capacity tends to decrease as the tree height increases (higher trees seem to reduce the number of trees harvested per hour). Total time excluding harvesting increases as the tree height increases, which suggests taller trees take more time to prepare for harvesting. Taller trees require more handling time, impacting overall productivity. Paradoxically, while increased time per tree reduces harvesting capacity, it improves efficiency, challenging the notion that faster harvesting is always better. These findings have significant implications for coconut farming practices.

Harvest planning should consider tree height variations, and a balance between speed and thoroughness is crucial. Ultimately, optimal coconut harvesting requires a nuanced approach that adapts to each tree's characteristics, potentially enhancing both productivity and long-term sustainability in coconut and mango farming Training programs should emphasize careful, efficient work over speed alone. This hydraulic ladder can be easily attached and detached as a single-point hitch or trail hitch to a minimum of 35 hp tractor with PTO. It also works in minimum undulated fields. It is also observed that, when the soil is in wet condition, it is difficult to stabilize the hydraulic ladder in the orchard

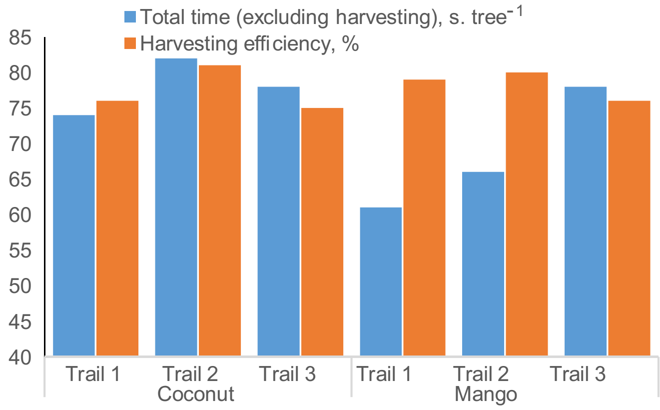

Fig. 4. Comparison of operating time and harvesting efficiency for the coconut and mango tree

fields. This ladder cannot be used for more than 12 m height crops especially coconut. To harvest the crop that has more than 12 m in height, the size of the trailer has to be increased for better stability and also stroke length of the stabilizers is also to be increased to achieve 16 m height from the ground level.

It is concluded that the coconut and mango harvesting capacity of the hydraulic ladder is 7 to 9 trees.h^{-1}and 130 kg.h^{-1} to 147 kg.h^{-1} for Rajgira variety. The hydraulic ladder works in such a way that it can be rotated in 360 degrees both at a clockwise and anticlockwise direction so that a minimum 4 coconut/ mango trees can be covered at one stand by simply operating the directional valve. The total time (excluding harvesting) required to operate the hydraulic ladder for coconut and mango trees is from 74 to 86 s.tree^{-1} and 61 to 82 s.tree^{-1} and harvesting efficiency of the hydraulic ladder for coconut and mango was found to be 75 to 81 percent and 76 to 80 percent, respectively. The cost of operation of the hydraulic ladder (inclusive of a tractor) for harvesting coconut and mango was 439 and 530 Rs.h^{-1}. Hydraulic ladder is suitable for harvesting coconut and other orchard crops, pruning of trees, and spraying over the tree canopy up to a height of 12 m. Due to the initial investment cost being more, the hydraulic ladder can be operated by giving to the farmers on a hiring basis for harvesting of mango and coconut up to the height of 12 m to generate more income and to reduce the payback period time. This will help the growers of coconut and mango to harvest the fruits and coconut without any damage ensuring consistent quality and reducing post-harvest losses. Additionally, they minimize fruit damage during the harvesting process, preserving the quality and value of the harvested produce. Ultimately, fruit harvesters can increase overall productivity and yield, making them a valuable tool for modern agriculture.

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Received: September, 2024; Revised: September, 2024; Accepted: November, 2024