INVESTIGATIONS ON PHYSICO-MECHANICAL PROPERTIES OF COCONUT PALM FOR THE DESIGN AND DEVELOPMENT OF A COCONUT PALM CLIMBER

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Summary and conclusions

5. SUMMARY AND CONCLUSIONS

A study was conducted to investigate the physico-mechanical properties of the coconut palm climber with the aim of developing a climbing device. To obtain the preliminary data required for the study, field investigations were carried out to identify the important physico-mechanical properties of the coconut palm. Instrumentation that was not available for measuring some properties was also developed as part of this study. A comparative analysis of the features of existing coconut climbing devices was performed to understand the pros and cons of these devices. Based on the preliminary findings and insights from the study of existing models, certain functional requirements for a climbing device were identified. Following this, a conceptual design was finalized. In line with these findings, a self-raising platform-type coconut palm climber was designed and developed to address the major drawbacks of existing models. Field evaluation of the developed palm climber was conducted, and the results were analysed and discussed.

5.1 PHYSICO-MECHANICAL PROPERTIES

Certain physico-mechanical properties of the palm that affect the design of a climbing device, such as the height of the palm, girth at different height levels, inclination of the palm with respect to the ground, hardness of the palm trunk, crown width, and leaf count were studied prior to the design of the climbing device. Data on these properties were collected from three districts of central Kerala and were analysed. Standard instruments available such as Hypsometer and Mantax Black caliper, were used for measuring the height and diameter of the palm trunk, respectively. Since no instruments were readily available for measuring inclination and hardness, new instruments such as the Inclinometer and Tree Hardness Tester were designed and developed for these purposes. The data collected on the physico-mechanical properties were analyzed and discussed.

5.2 COMPARATIVE STUDY OF EXISTING MODELS

A comparative study of some existing models of coconut palm climbers was conducted to identify their important features. Manual coconut climber models like Chemberi model, TNAU model, CPCRI model, KAU coconut palm climber, KAU Kera Suraksha, and Chachoos Maramkeri were selected for the study. Additionally, an engine-operated coconut climbing device was also studied. The features of these models were consolidated and tabulated for easy reference.

5.3 FUNCTIONAL REQUIREMENTS AND CONCEPTUAL DESIGN

Based on a preliminary study of the physico-mechanical properties of coconut palms and an analysis of the features of existing climbing device models, the following functional requirements were identified for designing a new coconut climber as listed below:

i. The device should be capable of replacing the strenuous efforts of manual climbing.

ii. It should enable operations such as harvesting coconut or tender coconut, neera tapping, crown cleaning etc with ease and safety.

iii. The coconut climbing device should function as a self-raising platform, eliminating strain on human muscles. The platform should be equipped with guardrails to ensure the climber can be safely elevated to the top of the palm, minimizing the risk of falls.

iv. The device should be designed to accommodate coconut palms with a minimum height of 12 meters, as preliminary studies indicate that the majority of palm heights range between 10 and 14 meters.

v. The trunk of the coconut palm should serve as a supporting guide for the raising platform. The device should include a secure fixture to prevent sliding away from the trunk while allowing smooth upward and downward movement, accommodating the varying girth dimensions of the coconut palm.

vi. It may be operated with a maximum of 1 hp power source.

vii. The device may be fitted on a trolley platform so that it could easily be taken to the coconut field and to the individual palm bottom.

viii. The device may be fastened to or detached from the palm trunk easily and there should be provisions for changing the directions and inclination of the device with respect to the palm trunk.

ix. The operation of the device should be easily controllable by the person climbing the palm. Additionally, provisions for a safe descent should be included to allow for quick and secure coming down in case of emergencies

Based on the identified functional requirements for a coconut palm climbing device, a conceptual design was finalized, and the subsystems were developed to meet these requirements

5.4 DESIGN AND DEVELOPMENT OF THE COCONUT PALM CLIMBER

A laboratory model of the extendable mechanism was developed prior to designing the palm climber to study the system's operation. This model featured three ladder sections that could be extended using a wire rope and pulley system, operated with a manual winch. Insights gained from the functionality of the lab model guided the design and development of the actual climber.

The components and sub-systems of the designed climbing device are:

a) Extendable Mechanism -The extendable mechanism comprises a telescopic rung ladder with three sections, each measuring 4.6 meters, designed to reach a height of 12 meters with sufficient overlap for stability. The ladder is constructed from heavy duty aluminum of grade 6000 for strength and durability. The width between the side rails for the base section is 460 mm, second fly section is 400 mm and first fly section is 340 mm. Each section features 15 'W'-shaped rungs for the steps. The 'W'-shaped design enhances grip and stability, offering greater structural integrity compared to traditional flat rungs. This design ensures safety and ease of use during climbing operations.

b) Hauling mechanism – The extension of the three-section rung ladder to its full length of 12 meters is facilitated by a hauling mechanism that includes a steel wire rope, a pulley system, a winch mechanism, and a power source.

c) A 6 mm diameter 18 x 7 steel wire rope is selected to pull the ladder fly section, which has 18 strands of 7 wires each with a load carrying capacity of 480 kg.

d) The winch mechanism, similar to an electric cable hoist, is designed to wind or unwind the wire rope by wrapping it around a rotating drum. The drum has a diameter of 80 mm and a length of 330 mm and is operated by an electric motor. The winch features a handle switch with ascending and descending functions to control the hoist. It also includes a limit switch with a buffer spring for emergency stops, ensuring safety during operation. Additionally, a remote-control switch is provided, allowing the climber to control the operation of the winch, enhancing convenience and safety.

e) The power required to lift the ladder and climber to a height of 12 meters is calculated based on the weight to be lifted and the desired lifting speed. The climbing velocity is assumed to be 0.14 ms^{-1}, which represents the average velocity of various types of coconut climbers. Based on these parameters, a 1 hp electric motor is selected as the power source to efficiently operate the hauling mechanism and lift the ladder to the required height.

f) Suitable speed reduction mechanism for the winch system with rotor diameter of 80 mm and speed reduction ratio of 60:1 is selected to get the desired climbing velocity.

g) The telescopic ladder is securely supported on the palm trunk using a top fixture ring that prevents the ladder from sliding sideways. Self-adjusting, spring-loaded rollers are incorporated within the top ring to accommodate the varying girth dimensions of the palm trunk corresponding diameters ranging from 20 cm to 32 cm, representing the minimum and maximum trunk diameters observed in the field.

h) Safety mechanism – A sturdy, trapezoidal-shaped basket is hinged to the top of the ladder section for operator safety, with a door secured by two locks. The guard rail height is 800 mm, and a 500 mm grab rail is provided, while the base length is 400 mm. The basket features a door for easy access and a 400 mm square plywood platform for stability. A safety harness is also recommended for enhanced protection.

j) Mounting fixture and transport aid – All the components are mounted on a trolley platform with provisions for rotational control and tilt control. The trolley is made of MS rectangular pipe, topped with a thick plywood board and 4 wheels for easy movement through the fields. Provisions for placing a generator set are also there on the transport trolley, when going to the fields where electric power connections are difficult.

5.5 CONCLUSIONS

The following conclusions were made by conducting experimental and field trials.

1. Physico-mechanical parameters such as the height of the palm, girth at different height levels, inclination of the palm with respect to the ground, hardness of the palm trunk, crown width, and leaf count, were studied prior to the design of the climbing device. Coconut palms of three districts of central Kerala viz. Malappuram, Thrissur and Palakkad were studied for this.

2. Height and diameter of palm trunk were measured using Hypsometer and Mantax Black caliper respectively. Two instruments namely Inclinometer and Tree hardness tester were developed for measuring inclination and hardness of live palm as there are no instruments readily available for those measurements.

3. The majority of coconut palms fall within the height range of 10 to 14 meters. In Malappuram and Palakkad districts, the highest frequency is observed in the 12–14-meter range, while in Thrissur, the 10 - 12-meter range shows the highest frequency. Overall, the most frequent height interval is around 12 meters. Therefore, the maximum height to which the climbing device can be extended is limited to 12 meters.

4. The analysis of the girth data from the collected coconut palm samples across the three districts reveals that over 90% of the palm's top diameters are above 20 cm. The maximum diameter observed at breast height (DBH) of the palm trunks is 31.8 cm. Hence, the top fixture ring is designed to accommodate palm diameters ranging from 20 cm to 32 cm.

5. The crown width of a tree refers to the width of its foliage as seen from a top view. It is measured using the vertical sighting method. The most frequent

crown width range is 8–10 meters in Malappuram and Palakkad, while in Thrissur, the range is 9–11 meters. Very large crowns (11–12 meters) are observed in Thrissur, while Malappuram has a slightly higher proportion of smaller crowns compared to Palakkad and Thrissur.

6. Across all three districts, 27-31 leaves are the most common range, with a significant number of palms in this category (Malappuram: 25, Palakkad: 27, Thrissur: 27). This reflects a general trend of healthy and mature palms with sufficient foliage. Very large leaf counts (32-36 leaves) are more frequent in Thrissur and Palakkad compared to Malappuram, indicating favorable growing conditions or management practices in these districts.

7. A simple instrument, called an inclinometer, was developed to determine the lean angle of a coconut palm trunk with respect to the ground. The instrument consists of a 180° protractor with a long straight base, a string suspended from the origin, and a plumb weight at the end. The plumb angle directly indicates the tilt of the palm from the vertical, while the angle with respect to the ground can be calculated using trigonometric principles.

8. The inclination is categorized into four groups: Erect, Slightly Slanted, Slanted, and Oblique. Analysis of the data revealed that 92.1% of the palms fall under the "Erect" category, 7.2% under "Slightly Slanted", 0.6% under "Slanted," and none under the "Oblique" category. This indicates that the majority of coconut palms in the sample grow upright with minimal or no leaning.

9. Hardness of the coconut palm is a salient property for ensuring the effective grip of coconut climbing devices, which directly impacts the outer layer of the coconut palm. It is also critical in determining the amount of force that can be safely applied to the trunk by the device.

10. To accurately measure the surface hardness of live coconut palm trunks, a specialized instrument, named the Tree Hardness Tester, was designed and developed. The components of the Tree Hardness Tester are Holding jaws, Support ring, Indentation tool, Load cell, Dial type depth gauge and a Spirit level.

11. Indenter tools made of high-carbon steel with three different head geometries — wedge, spherical, and square-are used to measure hardness. The hardness (N/mm^2) of coconut palm is measured by all the tools at four different penetration depths such as 1 mm, 2 mm, 3 mm, and 4 mm. All tools demonstrate a reduction in hardness as penetration depth increases. This reflects the structural properties of coconut palm, where the outer layers are denser than the inner layers, leading to reduced resistance with increasing depth.

12. Highest hardness recorded is 6.85 N mm^{-2} for sphere shaped tool. The Wedge tool experiences the sharpest decline in hardness with depth, suggesting that its penetration becomes easier as it moves deeper into the palm. This might be due to the wedge geometry reducing resistance with depth. The Square tool falls between the sphere and wedge in terms of hardness measurements and rate of decline.

13. Finite element analysis of the ladder fly section was performed using Solid works simulation tool to determine the deflection under an applied load. The analysis shows that the stress reaches a maximum value of 282 MPa for an applied load of 150 kg. The critical areas of stress concentration are observed at the corners and the junctions between the ladder's vertical and horizontal members. The yield stress is specified as 276 MPa, indicating that any part of

the ladder exceeding this stress level will undergo plastic deformation, potentially leading to failure.

14. The performance evaluation of the developed coconut palm climber was conducted in the field under both loaded and unloaded conditions. For climbing without a load, the average time to ascend a 12 - m tall palm tree was 35.33 s, with a speed of 0.34 ms^{-1}, while the descent took an average of 32.01 s at a speed of 0.38 ms^{-1}. When carrying a load, the ascent time increased to 99.39 s, with the speed reducing to 0.12 ms^{-1}. Similarly, the descent with a load was slower, taking an average of 88.45 s with a descent speed of 0.14 ms^{-1}.

15. To evaluate the economic feasibility of the developed coconut palm climber, a cost analysis was estimated using the straight-line method. The climber requires an initial investment of ₹95,000, has a lifespan of 15 years, and a resale value of ₹9,500. The total operating cost of the device is ₹240 per hour, while the cost of climbing per tree is ₹40, assuming six trees are climbed per hour.