Review of literature

2. REVIEW OF LITERATURE

This chapter illustrates a comprehensive review of relevant research work carried out related to coconut palm climbing and is briefly reported under the following headings.

2.1. Physico-mechanical properties of Coconut Palm

2.1.1 Physical parameters

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2.1 PHYSICO-MECHANICAL PROPERTIES OF COCONUT PALM

Despite the long history of coconut cultivation in Kerala and its status as a widely grown major crop, there is surprisingly limited knowledge about its structural features and physical growth parameters.

2.1.1 Physical parameters

Gillman and Watson, 1993 studied the general features of coconut palm. It is considered as one of the most valuable and useful plants for mankind. The botanical description on height and crown spread indicates a range of 50 to 60 feet and 15 to 25 feet respectively.

Chan and Elevitch, 2006 conducted a detailed study on *Cocos nucifera.* The study includes distribution, botanical description such as size of crown, length of leaves, genetics features of tall and dwarf varieties, plant species, growth and development, pests and diseases, agroforestry practices, etc. Authors convey that an 80-year-old coconut palm may attain a height of 35-40 m.

Crop parameters such as girth and height of 25 coconut palms were studied by Jaikumaran *et al.,* (2016). Girth measurements were done at three specific height levels of the coconut palm, at one meter above ground level, one meter below the lowest crown level and at the middle portion. They observed a diameter range of 20 to 32 cm and height range of 2 to 30 m.

Manoharan and Megalingam, 2019 analyzed coconut tree structure as a background work for the design of an unmanned robotic harvester. The study covered a detailed description of diameter, height and inclination of the tree trunk. The maximum and minimum height of the coconut palm recorded was 15.2 m and 2.6 m respectively. Average inclination of coconut palm was 16°. The average value of base circumference and circumference at a height of 1.5 m from ground was 95 cm and 71 cm respectively.

Megalingam *et al.*, 2023 developed a "computerized coconut tree detection system" for designing and easy use of robots in the harvesting sector. Three parameters viz. height, inclination and orientation were considered for the study. These factors play a crucial role in assessing the health and growth of coconut trees, shaping the design and application of robots used in coconut harvesting.

2.1.2 Coconut wood characteristics

Density of coconut wood decreases with vascular bundle frequency moving from the outside of the stem to the middle of the stem and also up the stem from the base (Fathi and Fruhwald, 2014). The location and age of the tree affect the density distribution of coconut palm wood. Mature coconut palm trees typically have three primary sections to their trunk: the core, the inner shell, and the outer shell. The outer shell, sometimes referred to as the "husk," is a fibrous covering that envelops the tree's entire trunk. It has a low density and is lightweight. Although it is not used for commercial reasons, this layer offers some protection to the trunk's inner layers. The denser layer of the stem surrounding the core is called the "mesocarp," or inner shell. The least dense portion of the trunk is called the "endocarp," or core, and it is situated in the middle of a tree. (Fathi *et al.*, 2023).

Fig. 2.1. Cross sectional view of Coconut wood (Fathi *et al.*, 2023)

2.1.3 Hardness

A hardness test is usually conducted by pressing a precisely sized and weighted indenter into the surface of the material being tested. The hardness is determined either by measuring the depth of the indenter's penetration or by assessing the size of the impression it leaves. Doyle and Walker, 1985 studied indentation hardness of coconut wood and reviewed the advantages and disadvantages of the methods used. The Janka hardness test evaluates a wood sample's resistance to denting and wear by measuring the force needed to embed a steel ball with a diameter of 11.28 millimeters (0.444 in) halfway into the wood. This process results in a hemispherical indentation with an area of 100 mm^2. Conical or pyramid shaped tool was also tested. A new method of finding hardness using a wedge indenter was suggested.

Structure properties of fibers from various parts of coconut palms were examined by Satyanaraya *et al.,*1982. The internal structure and chemical properties have a relation with the observed properties like size, density, tensile strength etc.

Doyle and Walker (1985) conducted studies on historical context for the wood hardness testing process, offering an overview of the strengths and weaknesses associated with the existing methods. It explores a novel approach involving Janka ball, Brinell ball, Cone, Monnin Cylinder and Wedge indenter that includes a discussion of the deformation patterns beneath the indenting tools.

The design of hardness testers is complicated, yet their principles, operation, and application are simple (Bentley, 2021). These instruments measure a material's hardness by assessing its capacity to withstand permanent deformation under an applied force. Various hardness testers employ diverse methods for this purpose—some correlate the depth and configuration of the indentation formed in the material by a predetermined force applied to the surface over a specific duration. Others determine the material's resistance to a spring-loaded force or measure the velocity of an object rebounding off the surface (Velling, 2020).

Gilman and Watson, 1993 analyzed the features of the bark of coconut trunks. The trunk typically grows in an upright manner and does not sag or droop. Also, the trunk was said to be breakage resistant.

Ewart, 1995 developed an advanced prototype wood hardness tester for detecting decay in aspen stands. The device operates by measuring how deeply a spring-loaded needle penetrates fresh or frozen wood. The hardness tester can determine the two different stages of fiber deterioration. An electronic display shows the needle's penetration depth, which can be used to estimate wood hardness, indicating the type and extent of decay.

Strength, stiffness and growth strain of coconut palms were studied by Huang *et al.*, (2002), Gonzalez *et al., (*2014), Matsuoka (2000). They developed a method to find the hardness of wood in standing woodpecker nesting trees. The concept behind the method was to measure the force required to deform wood tissue using an increment borer.

Voros and Nemeth, 2020 reviewed on the history of wood hardness tests. Five methods for finding hardness of wood were considered- ball hardness, cone hardness, needle hardness, wedge hardness and cylindrical hardness. For industrial purposes, mainly two methods are followed- Janka hardness and Brinell-Morath hardness.

There are various forms of hardness, along with numerous tests and scales. Hardness can be categorized into three primary types: scratch resistance, static indentation, and dynamic indentation. Various shapes of indenters are utilized for static permanent indentation. Sharp-edged indenters like cones (Rockwell test), regular pyramids (Vickers test), or extended pyramids (Knoop test) are effective for hard materials. Conversely, rounded indenters like balls (Brinell, Janka, Krippel, and Meyer tests) and cylinders (Monnin test) are more suitable for testing wood (Koczan *et al.,* 2021).

Comparative Evaluation of Physical and Mechanical Properties of Coconut (*Cocos nucifera*) Timber in the Radial Positions were carried out by Fairoosa and Nair (2022). The result obtained indicated that, on both sides and ends of the coconut timber, the resistance to the indentation (hardness) is greater at the dermal position (1207.61 kg, 767.65 kg) and less at the core position (252.587 kg, 359.31 kg).

Hardness of surface-densified wood was evaluated by Scharf *et al*., 2022. This study assessed the impact of the hardness test parameters, such as applied load and indenter shape, on the observed hardness as well as the density profile of surface-densified wood. Depending on the hardness test conditions, the density profile varied significantly. The hardness of surface-densified wood should be assessed using either product-specific hardness test criteria or the density profile itself.

2.2 COCONUT HARVESTING

Coconut climbing is a traditional skill and art of ascending coconut trees to harvest their fruits or access other valuable resources such as palm sap or leaves. This ancient technique requires strength, agility, and experience, as coconut trees can grow up to 100 feet (30 meters) tall and have unbranched trunks, making them challenging to climb (Doring, 2022). In some regions, coconut climbing has become a tourist attraction, where visitors can witness the skilled climbers in action and sometimes even try climbing themselves under supervision as part of their plantation visit (Kerala tourism, n.d).

Various palm climbing techniques showcase remarkable human ingenuity. These include

- Climbing the palm with bare hands (Jahan *et al*., 2018)
- Climbing with a piece of rope (loops) (Sethupathi *et al.,* 2020) (Fig. 2.4)
- Climbing with specially designed spikes attached to feet (these spikes may cause damages to the trunks) (TCIA, 2017)
- Climbing with different types of ladders (Mani and Jothilingam, 2014) (Fig. 2.5)
- Making steps in trunks by carving (damaging) (Manoharan and Megalingam, 2019)
- Making steps on trunks by attaching coconut husks with ropes on trunks (non-damaging) (Padre, 2018)

- Using climbing devices which work based on using only human power- standing type and sitting type (Edacheri *et al.,* 2011)
- Using extra power sources (Kolhe, 2015)
- Using robots or other unmanned vehicles for harvesting (Dubey *et al*., 2016), or
- Even using trained monkeys to climb up the palm and harvest (Ehelepola *et al.,* 2017) (Fig. 2.2)

2.2.1 Traditional harvesting methods

The traditional method of harvesting the nuts for dwarf trees is using a knife with bamboo sticks (Kerure *et al.,* 2016) (Fig. 2.3). For tall coconut trees, climbing was done manually, which was not only time-consuming but also hazardous for climbers. It is the most common and conventional method of harvesting coconuts, generally practiced by trained and experienced workers. Based on the movement followed for climbing, traditional methods can be classified as frog foot type, front foot type, pole type, ladder type and walking type (Kushwaha and Singh, 2015; Sethupathi *et al.,* 2020).

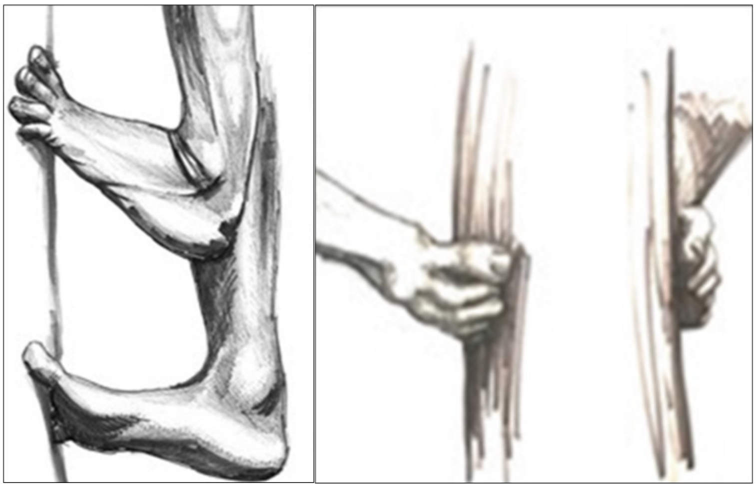
Fig. 2.2. A man and a trained monkey climbing a coconut tree in Malaysia to harvest coconut. (Ehelepola *et al.,* 2017)

Fig. 2.3. Coconut harvesting using pole and knife

Fig. 2.4. Coconut harvesting using straps

Fig. 2.5. Coconut harvesting using bamboo pole with steps (Filinto, 2015)

The front foot type (Fig. 2.6. (a)) of climbing coconut tree is similar to rock climbing (Senthilkumar *et al.,* 2015). The climbing person has to hold and lock his hands on the back of the trunk. Keeping pressure on the trunk using his front portion of the foot, the person has to alternatively move his hands and foot. Although it appears to be the simple to learn, it does need solid skills, arm strength and balance (Edacheri *et al.,* 2011).



(a) (b)

Fig. 2.6. (a) Front foot technique (b) Frog foot technique
(Hanna and Venkataraman, 2022)

The other technique is the frog-foot type (Fig. 2.6. (b)) climbing whereby the climbers put the legs on two sides of the trunk-bent and splay outward like a frog. It is considered to have a speed of 0.5 m/s. It requires greater arm strength to hold the individual’s weight (Kushwaha and Singh, 2015).

Pole method uses a scythe attached to a long bamboo pole or some PVC, GI, aluminum pipes to detach the nut from the palm. Variety of extendable telescopic poles with blades or pluckers are now available in the market. The advantage of this method is that it is comparatively faster, efficient and comparatively less dangerous and tedious compared to climbing methods. This helps in easy harvesting of nuts. The drawback is that, height of the coconut palm must be within a certain limit. In certain regions, drains are dug in coconut plantations between the rows of coconut palms, so the coconuts drop into the body of water which cushions the falling impact (Tetrapak, 2016).

2.3 HISTORY OF CLIMBING DEVICES

Introduction of climbing devices for palms is one of the distinctive innovations in the agricultural field and helps to reduce harvesting losses and improves working conditions. The development of coconut climbing devices has undergone significant advancements, combining traditional techniques with modern engineering principles. These devices are designed to assist farmers in climbing coconut trees efficiently and safely, reducing the physical strain and potential risks associated with manual climbing. These climbing devices can be classified as manual, self-propelled, tractor operated and unmanned types (Kushwaha and Singh, 2015).

2.3.1 Manual coconut palm climbing device

Horace (1985) created a palm climbing apparatus (Fig. 2.7). It consisted of a climbing platform with a platform yoke that supported the user with a seat. It also had a folding foot support with a foot support yoke. A cooperating foot platform supported the user intermittently. While climbing, the platform was pushed upward by the platform yoke and foot support yoke. Both the platform yoke and the foot support yoke have a Y-shaped segment.

A hybrid climbing and hang-on palm stand with an optional climbing aid created by Williams (1989) is shown in Fig. 2.8. It features a platform, a folding seat that can be adjusted to sit either above or below the platform, and a climbing band that encircles the palm. To provide stability, the band, seat, and platform engage the palm at three different points. A Chinese knot was supplied to tighten the safety rope against the palm, and it was fastened to the seat. A climbing aid was made available, which mostly consisted of a rectangular frame with one "end frame member" that could be pushed toward or away from the other "end frame member" to lock in a desired position based on the palm's circumference.

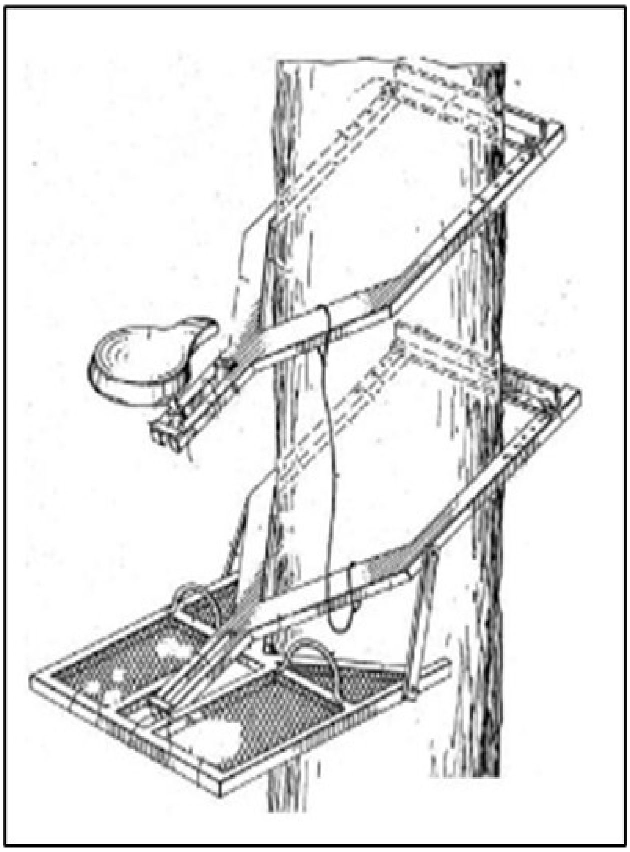


Fig. 2.7 Palm climbing apparatus - Horace model (1985)

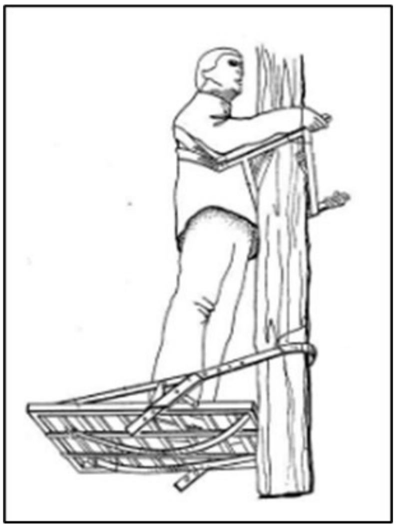


Fig 2.8 Hang on type palm climbing aid - William Model (1989)

Morris (2002) designed a palm climbing stand (Fig 2.9) featuring a base frame, two platforms, and two arms. Each arm included a support arm and a blade attached to the base frame. The first and second arms were pivotally connected to the base frame and could be securely engaged with the support arm when needed. The support arm had a curved section at the opposite distal end of the first arm. A foot support lifting bracket was affixed to the base frame of the second platform. The lifting bracket for the foot support was made of a stiff, non-flexible material.

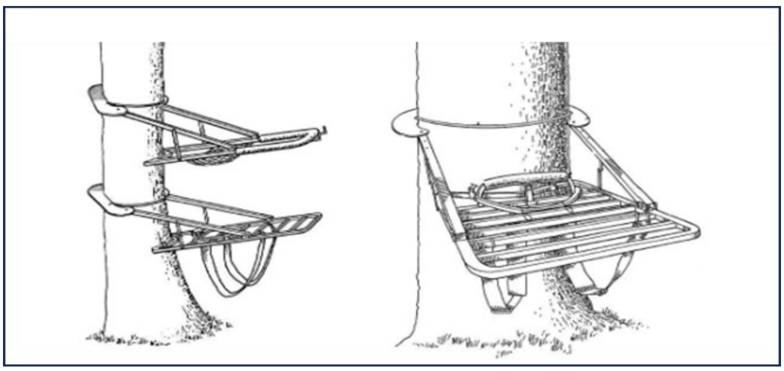


Fig. 2.9 Climbing palm stand –Morris model (2002)

Mr. M. J. Joseph 2002, a farmer from Chemberi village in Kerala's Kannur district, invented a mechanism for climbing coconut palms. It is known by the names Chemberi model, Appachan model or Joseph model (Fig. 2.10, Fig.2.11). There are two frames on the gadget (left and right). Each frame is made up of a semi-circular palm gripping pad made of used tire rubber that is fitted against the palm trunk and a flexible, adjustable iron rope that surrounds the palm. The iron rope is divided into two ends, one of which is fastened to the rubber pad and the other to holes that may be adjusted to change the length of the rope based on the palm's circumference. By the simultaneous movement of hands and legs, both loops are lifted. This simple yet highly effective tool is particularly valuable for trained users. It has gained widespread acceptance across Kerala and has also become popular in rural areas of Tamil Nadu and Karnataka. The Research Testing and Training Centre (RTTC) in Vellayani, Kerala and the District Industries Center awarded the inventor a certificate of recognition for this. Kerala State Agricultural The innovator received an award at the Second National Innovation Award Ceremony in 2002, organized by the National Innovation Foundation. In 2009, the climbing device was granted a patent (India Patent No. 194566) (Anand, 2014).

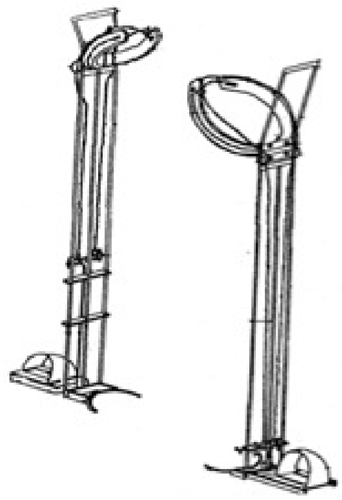


Fig.2.10 Chemberi model coconut climbing device (IPR, 2009)

Fig.2.11. Chemberi model coconut climbing device (Anand, 2014)

Fig.2.12**.** Standing type climbing device- Joy Varghese (Outlook, 2011)

Modifying the Appachan model, Joy Varghese made a climbing device (2006) and took patent over Coconut Palm Climbing Machine. It is an easy to use and handy type machine, which can be used even during the rainy season without being slippery. It consisted of a frame made with steel rod, wire ropes with rubber grips, MS pipes as handle and MS flats as foot rest. (Fig. 2.12). The working principle is the same as that of the Appachan model. The only difference is with the construction of the frame (Outlook, 2011).

Agricultural Machinery Research Centre of Tamil Nadu Agricultural University, Coimbatore under All India Coordinated Research Project on Farm Implements and Machinery has developed a sitting type coconut climbing device-TNAU model (2006) shown in Fig. 2.13. It consists of two components -upper frame and lower frame (Krishnan *et al.,* 2013).

The tubular upper frame component consists of a user-accommodating seating arrangement, a front support rail, a cross-back rail, and side rail. The seat is a flexible sagging type made of rexine fabric. A rubber bush on a square tubular bar serves as the gripping aid. Two of the detachable grasping elements are affixed in a "V" pattern to the front support bar of the seating frame, while the other one is fastened to the extending arm. With the use of an extending arm, the distance between the gripping members can be altered to accommodate the circumference of the coconut palm.

Lower frame member is a tubular frame work with a rigid base section and a palm gripping section. The rigid base section is situated next to the palm trunk to support the user's weight when the upper frame is repositioned on the coconut palm. The user can insert his feet and raise the unit by using the pair of parallel tubular bars with rubber bushes that are carried by the sturdy base portion. Additionally, there is cushioning material surrounding the rubber bushes for the user's feet.

The upper and lower frame members are connected with a canvas belt to prevent them from slipping down the palm trunk. The user can raise the device and move it up or down the palm using the handles provided on the side rails of the upper frame. When the unit reaches the top of the coconut palm, it can be attached to a frond using a hook to allow the user to collect coconuts.

Fig. 2.13. TNAU model climbing device (Krishnan *et al,* 2013)

A sitting type coconut tree climber was developed in Tamil Nadu, by an agriculturist D. N. Venkat- Multi Tree climber (Fig. 2.14). It has two portions, upper frame and lower frame. The upper frame is operated by hand and the lower portion with seating provision is operated by legs. Climbing occurs by the up and down movement of the upper and lower frame. The operator can sit comfortably on the seat. A locking system and safety belt are provided as an additional safety. The time required for climbing 40 feet height is considered to be around 5 minutes, which includes the fixing time, climbing up and down and removing the device from the palm. It fits trees with different girths.

Fig. 2.14. Multi tree climber (GoI, n.d)

Fig. 2.15. CPCRI model coconut tree climbing device (Mathew, 2020)

Coconut and areca nut palm climbing device-CPCRI model (Fig. 2.15) was developed by ICAR-Central Plantation Crops Research Institute. It consists of a pair of square shaped U frames. Foot rests are provided at the open ends (longer arm) of the frames. The length of the middle arm of the U frame can be adjusted according to the size and girth of the palm. By wearing the shoes, the device is attached to the operator. It is a patented model by CPCRI.

KAU coconut palm climber (Fig. 2.16) is a modified version of TNAU coconut palm climber. It has two parts- upper frame and lower frame. The material used for construction of the upper frame is Galvanized iron and the lower frame is Aluminium. For gripping, rubber bushes are provided in both the frames. Specially designed foot wears are provided on the lower frame. In order to keep the upper and lower frame in parallel position and in more stable position, 'U' shape in the frames is made with an inclination to the horizontal (Jayan, 2015).

Jaikumaran *et al.,* (2016) designed a coconut climbing device at Agricultural Research Station, Mannuthy, KAU (Fig. 2.17). This sitting type climbing device was a modification made to the TNAU model with two units. It is made of mild steel pipe. The upper unit consists of a seat frame section and an adjustable palm attaching section. Seat frame section includes a seating arrangement, rear support frame with a safety rope and seat support. The seat support and adjustable palm attaching sections are connected. Lower unit consists of a foot frame section and a palm attaching section. Metal wire ropes are provided at both units for gripping at the palm attaching section.

Fig. 2.16. KAU Coconut Palm Climber (Jayan, 2015)

Fig. 2.17. KAU Kera Suraksha coconut climber (Jaikumaran *et al.,* 2016)

Performance evaluation and modification of existing TNAU model coconut tree climbing device was carried out by Sridhar *et al.,* 2017 (Fig.2.18). Problems such as heavy weight of the lower part, improper arrangement of gripping aid on removable shaft were highlighted and modifications were done. The upper frame was made of a tubular frame with a rigid base and an adjustable curved gripping section. Seat was made of flexible sagging type rexine fabric. The lower frame was made of mild steel rod of 8 mm diameter with an attached adjustable encircling iron rope. Additional lock is provided at the center of the foot rest along with a safety strap.

Fig. 2.18 Modified coconut climbing device (Sridhar *et al.,* 2017)

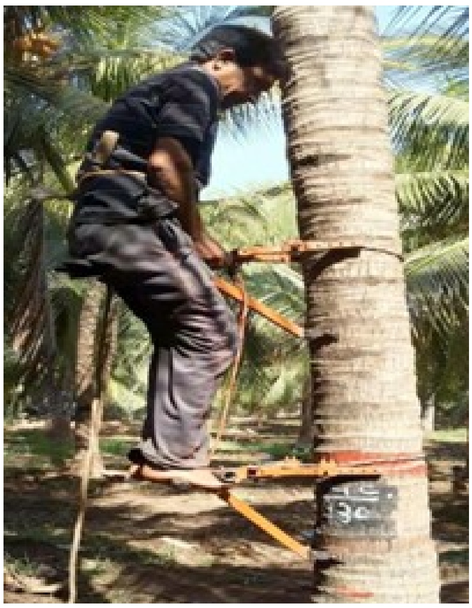


Fig. 2.19. JAU model (Agravat *et al.,* 2018)

A sitting type coconut palm climbing device was developed at Junagadh Agricultural University by Agravat *et al.,* 2018 (Fig.2.19) which consists of mainly two parts -upper unit and lower unit. The key parts of the climbing device were four number of approach section (upper right, upper left, lower right and lower left), two number of junctions (upper and lower), gripping face plate (for grip with trunk), seat and seat support pipe, telescopic pipe with metal rope and feet rest. The device weighs around 4.5 kg and the payload is almost 160 kg.

2.3.2 Mechanical coconut palm climbing device

There are a number of models of tree climbing devices developed by many farmers, engineers, institutions and companies. Out of this, the most popular models were reported.

Kolhe, 2014 tested and ergonomically evaluated tractor mounted and self-propelled coconut climber for coconut harvesting. The different methods of coconut climbing -manual, mechanical and Tractor Mounted Hydraulic Elevator (TMHE) were considered for the comparative study. Factors like efficiency, safety and risk of harvesting were more for manual and mechanical methods. Further development for Tractor Mounted Hydraulic Elevator (TMHE) was carried out and Tractor Mounted and Self-Propelled Coconut Climber (TMSPCC) was developed by considering the drawbacks of the above methods.

M/s Mabens Engineering Solutions, Shimoga has developed a ‘man carrying bike’ specifically designed for climbing up coconut trees. This innovative machine is powered by a 2.5 HP petrol engine, enabling it to climb up to 90 trees per litre of fuel. With a load-carrying capacity of up to 90 kg, the bike is constructed from durable stainless steel and weighs 45 kg. Approximate Cost of the device is Rs. 1,25,000 (Maben, 2020).

Fig. 2.20 Tractor mounted and self-propelled coconut climber for coconut harvesting (Kolhe, 2014)

Fig. 2.21. Man carrying bike developed by M/s Mabens Engineering Solutions, Shimoga

2.3.3 Unmanned coconut palm climbing devices

An automated coconut harvester prototype ‘treebot’ was developed by Senthilkumar *et al.,* 2015 (Fig. 2.22). Three DC geared motors each were used to drive the body and arm of the device. Wheeled design gave the advantage of avoiding legs which requires more joints and degree of freedom. Toothed rotary blades were used as an end effector.

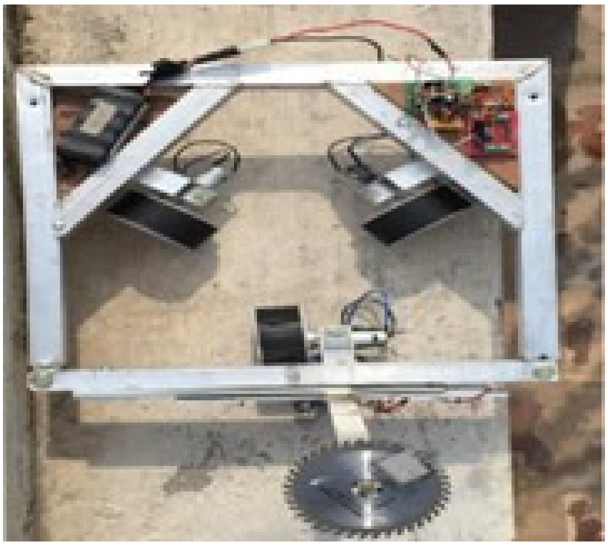


Fig. 2.22 Treebot (Senthilkumar *et al.,* 2015)

Fig. 2.23 Top view and front view of harvesting device (Dubey *et al*., 2016)

Dubey *et al* (2016) conducted studies to make use of intelligent machines popularly working in industrial areas to coconut climbing device and harvesting device (Fig.2.23). This low-cost machine mainly consists of two segments, connected by two threaded rods which in turn are coupled to motors. The working and kinematics are the same as the available coconut harvesters. Aluminum segments and threaded rods are used for manufacturing. Six motors are used for the movement of the machine. It has a robotic arm for separating the nuts from the palm. The operation and control is manual and is done from the ground using a remote. The automation is done using Arduino-Uno, sensors and other circuits.

Azarudeen *et al.,* 2018 designed a low-cost automated coconut tree climbing device made of Galvanised Steel (Fig.2.24). The main components are a 12-V DC battery as power supply, 3 axis robotic arm, three DC motors -two for gripping and one for vertical motion and four servo motors for robotic arm movement. Compression springs are also added for the smooth movement of the wheels. A rotor blade is attached at the tip of the robotic arm which acts as an end effector. Visual sensors are used for identifying the bunch of coconuts to be harvested.

A pneumatic coconut tree climber and harvester (Fig. 2.25) was designed and fabricated by Dinesh and Muthukumar (2020). Hexagonal clamps were used as the trunk attaching part. Pneumatic double acting cylinders were used for the upward and downward motion, DC motors for angular movement and cutting operation.

Amaran (Fig. 2.26), a new robot, was designed to climb coconut trees. Amaran has a robotic arm and a cutting tool that can be attached to a ring-shaped frame that fits around a coconut tree. It can be controlled remotely using a wireless connection or a smartphone app. To harvest coconuts, Amaran is positioned near the coconut bunch and the cutter is activated to cut the stem connecting the bunch to the tree.he robot's ability to climb and harvest coconuts can be influenced by the tree's height, width, and angle. Test results showed that Amaran can successfully climb trees up to 15.2 meters tall, with circumferences between 0.66 and 0.92 meters, and inclinations of up to 30 degrees (Megalingam *et al,* 2021).

Fig. 2.24 Automated coconut tree climbing device (Azarudeen *et al.,* 2018)

Fig. 2.25 Pneumatic coconut tree climber and harvester (Dinesh and Muthukumar, 2020).

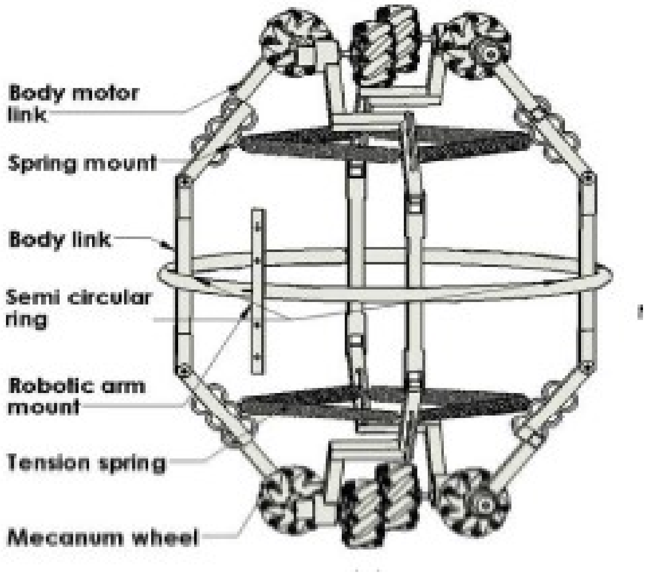


Fig. 2.26 Amaran (Megalingam *et al,* 2021)

2.4 ERGONOMIC STUDY OF PALM CLIMBERS

Ergonomic study and evaluation involve assessing the interaction between humans and their work environment. The primary aim of ergonomics is to enhance human well-being and overall system performance by optimizing the interaction between humans and their work, tools, equipment, and environment.

Balachandran *et al*., 1992 examined occupational dermatosis in fifteen coconut palm climbers from the Central Plantation Crops Research Institute in Kasaragod, India, who were between the ages of thirty and forty and had been working in the field for ten to twenty years. Additionally, they were watched as they climbed in order to examine the method used. The majority of the climbers used their hands and feet to hold coir climbing ropes. The outer husk of the coconut is used to make the stiff, gritty fiber known as coir. Every one of the fifteen climbers had scaling and lichenified plaques on the dorsal surfaces of their hands and feet.

In some climbers, callosities were noted over the medial portions of Thenar eminence (Thumb area).

Occupational marks in a coconut tree climber were studied by Kumari *et al.,* 2006. Approximately 6% of instances of occupational skin illnesses are primarily caused by mechanical trauma, which is a common occurrence in many industries. The most prevalent kind of mechanical trauma is friction- ranging from mild interrupted friction that causes lichenification and hyperpigmentation to stronger, more persistent friction that causes callosities and damage to nails. Factors like age, sex, humidity, perspiration, infection, nutritional state, and genetic and racial makeup might alter the impact of trauma. Friction blisters are rare on loose, easily-stretched skin, although they can also happen with abrupt shearing force.

Health of coconut tree climbers of rural southern India were surveyed and studied by (Bincy *et al*., 2012). A total of 240 coconut climbers were interviewed. Data was gathered through a survey, focusing on incidents of falls, injuries, alterations in skin or body parts, and the frequency of individuals leaving their occupation. They were grouped into four.15 % of volunteers with less than 10 years of experience in group 1, 26.6 % in group 2 (with 10-20 years of experience), 44 % in group 3 (with 20-30 years of experience), and 41.3% in group 4 (with more than 30 years of experience) experienced falls from trees, resulting in injuries. Additionally, 7.7 % of volunteers in group 1, 15.0% in group 2, 16.9 % in group 3, and 12.0 % in group 4 had histories of accidental cuts/lacerations from special knives, as well as skids/slips during the monsoon season. Climbers in groups 2, 3 and 4 showed significant declines in body weight and BMI compared to non-climbers. Medical emergencies such as Colles, vertebral, and maxillary fractures, tendo-calcaneus lesions and severe allergies were among the reported incidents.

Ergonomic evaluation of climbing practices for assessing their suitability for coconut harvesting by manual climbing, mechanical climbing and climbing using Tractor Mounted Hydraulic Elevator (TMHE) were studied by Kolhe (2014). A new harvesting mechanism using Tractor Mounted and Self-Propelled Coconut Climber (TMSPCC) was developed which reduced the drudgery and hazardness of coconut harvesting. The stability, safety, and harvesting efficiency were seen to increase. The average working heart rate was reported as 122.94 beats per min in TMSPCC while it was 134.49 in conventional methods.

Three models of coconut climbing devices were ergonomically evaluated for assessing the suitability of the user by Mohankumar *et al*., 2013. FIM model (TNAU model), Kerala model (Chemberi model) and commercial model were selected for the study. Ergonomic improvements were made to the FIM model to enhance the user's comfort, safety, and ease of operation. The ergonomically refined coconut tree climbing device significantly increased the comfort and safety for male users. This enhancement resulted in a reduction of 7.8%, 12.2%, 10.7%, and 20.5% in heart rate, energy expenditure, overall discomfort rating, and body part discomfort score, respectively. Additionally, there was a 2.6% increase in overall safety and a 4.1% increase in ease of operation rating compared to the FIM model.

Low-cost coconut tree climbers for small farmers were developed in Bangladesh by Jahan *et al*., 2018. Trees with 23 - 40 feet heights were considered for testing the device. Ergonomic evaluations were done for operators with different age, height and weight. The evaluation focused on measuring blood pressure and user feedback regarding discomfort, safety, and overall usability.

Safety and efficiency aspects of various coconut climbing devices specifically for women was assessed by Sam et *al.,* 2019. Five existing models of coconut climbing devices: the sit and climb type (TNAU model), standing type (Chemberi model), KAU coconut palm climber (developed at KCAET, Tavanur, KAU), Kerasureksha (model developed at ARS, Mannuthy, KAU) and CPCRI model coconut climbing device were chosen for the study. The evaluation focused on ergonomic factors for women operators. The study revealed that the KAU coconut palm climber exhibited the lowest heart rate and energy expenditure compared to other models. Operators reported feeling less secure when using the TNAU model and the standing type (Chemberi model). The sit and climb type (TNAU model) were identified as particularly challenging to operate in comparison to the other devices. Based on these findings, it was concluded that the KAU coconut palm climber was the most suitable and ergonomically comfortable option for women operators.

Operator workload analysis on coconut tree climbing using portable coconut climbing equipment was carried out by Dhafir *et al.,* 2021. The operator's workload was calculated based on heart rate measurements, taken during coconut tree climbing activities. The workloads analyzed were qualitative and quantitative workloads. The traditional method of climbing consumes energy at a rate of 3.29 kilocalories per hour per kilogram of the operator's weight, whereas using portable climbing equipment increases the consumption to 3.82 kilocalories per hour per kilogram of the operator's weight. However, in terms of operator safety, the use of portable equipment has a higher level of security because there are footrests and handrails as well as seat belts.

2.5 PERFORMANCE EVALUATION

Performance of paddle type (Chemberi model) and push up type (TNAU model) coconut climbing devices were evaluated by Singh *et al*., 2012. Climbing efficiency of the devices were computed on the basis of number of trees climbed per day. The research clearly indicated that among the two commercially available climbing devices, the Chemberi Joseph model stood out as the superior alternative to traditional climbing methods. It offers improved climbing efficiency, user-friendliness, and better ergonomic suitability. Conversely, the TNAU model was easy to learn but was not commercially viable in its current form due to its time-consuming operation. Additionally, the device's weight poses a challenge. Experienced climbers of traditional methods might not perceive the need for safety measures. However, newcomers in this field express the necessity for a safety attachment to the Chemberi Joseph model, prioritizing climbers' safety and comfort.

ICAR-Krishi Vigyan Kendra, Chitradurga conducted training programmes to unemployed young individuals in rural agricultural areas in collaboration with Coconut Development Board, Cochin and compared the performance. Using traditional methods for coconut climbing, a person could climb approximately 10-25 trees per day, leading to meager earnings of Rs. 5,000-15,000 per year. After using the Chemberi model coconut tree climber, annual income surged to Rs. 20,000-60,000 and individuals could climb coconut trees exceeding 80-100 feet without any life-threatening risks. This innovation also enhanced harvesting efficiency to the range of 50-80 trees per day (Kerure *et al*., 2016).

2.6 CLIMBING MECHANISMS

The coconut climbing equipment incorporates a variety of mechanisms designed to provide stability, support and ease of use during the climb. From basic foot and hand grips to advanced mechanized systems, these systems were designed to reduce the physical strain and risk associated with climbing. These devices aim to provide an easy way to climb the tree in a safer, effective way.

2.6.1. Foot and Hand Grips

Foot Pedals or Straps: These are sturdy pedals or straps that allow the climber to secure their feet. They provide a stable platform to push against while climbing.

Hand Grips: These grips, often made of rubber or other non-slip materials, provide a secure hold for the climber's hands, reducing the risk of slipping (Mohankumar *et al.,* 2013).

2.6.2. Motorized or Hydraulic Systems

Motorized Climbing Devices: These advanced devices use a small motor to power the ascent, reducing the physical effort required. The motor drives a mechanism that moves the climber upward along the tree (Afonso *et al.,* 2015).

Hydraulic-Assisted Devices: Similar to motorized systems, hydraulic devices use fluid pressure to assist in climbing, making it easier to ascend tall trees (Dubey *et al.,* 2016).

2.7 SAFETY HARNESS SYSTEMS

Waist Harness: A harness worn around the waist that is attached to a safety rope or belt. This provides support and distributes the climber's weight evenly, reducing strain on the legs and arms.

Full-Body Harness: This system includes both a waist and shoulder harness, providing more comprehensive support and safety during the climb (Prabaswari and Al-Bana, 2024).

2.8 ROPE AND PULLEY

Wire ropes, also known as steel cables, are commonly used in applications that require high strength and flexibility. They are commonly used in hoisting equipment, drilling rigs, textile industry, supporting bridges and towers, or in elevators and cranes. They are designed to withstand heavy loads and are ideal for applications where flexibility and strength are paramount. Ropes are used for power transmission over long distances. Ropes are generally of circular cross-section and require grooved sheaves or pulleys (Seyhan, 2022).

Steel wire rope is distinguished not only by its constituent parts (wires, strands, core), but also by the arrangement of the strands around the core and how the individual wires are laid together to form strands. When the following requirements are met, the construction of the steel wire rope is defined.

- Number of wires in a strand
- Type of strand (strand design)
- Number of strands
- Type of core
- Lay direction (steel wire rope and strand)
- Pre-forming (Randers Reb, 2023)

The advantages of using wire ropes include- lightweight, operate silently, endure shock loads, exhibit enhanced reliability, no sudden failure. Additionally, they offer high durability, high efficiency, and low cost (Khurmi and Gupta, 2005).

A rope-operated extension ladder refers to a double or triple extension ladder that utilizes a system involving ropes and pulleys to extend and retract the ladder. Rope Operated Extension Ladders offer the fundamental advantages of traditional Extension Ladders, such as being tall, safe, sturdy, and portable. However, they go a step further by introducing a significant benefit: they require less effort to adjust their height. Unlike regular extension ladders, which need to be taken down for adjustments, Rope Operated Extension Ladders utilize a rope pulley system, allowing for height adjustments without the hassle of dismantling the ladder. These ladders ensure a safe and robust access solution, made convenient by the easy-to-use rope operation system (Ladderstore, n.d.).

An electro-mechanical ladder was fabricated by Patil *et al.,* 2019 using rope and pulley. It consists of an aluminum ladder, an electric motor, a wire rope, a load carrier made of mild steel, and a pulley for rope movement. The base is equipped with wheels, and a remote control is provided for operation. When electric power is supplied and the remote is activated, the motor starts running at its designated speed, pulling the load carrier upward through the pulley system. Pressing the reverse button causes the load carrier to move downward. This process facilitates the lifting and lowering of the load placed on the carrier. The remote allows precise control to stop the load at the desired height. Additionally, an emergency button is incorporated to halt the operation in case of emergencies.