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Full Length Research Paper

Development of ergo refined coconut tree climbing device

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Climbing coconut trees is an important activity in rural agricultural wage workers. Generally, skilled workers are employed to collect the coconuts from the tree. Agricultural workers employed for coconut tree climbing suffer musculoskeletal disorders than any other type of injury or illness. The developed tree climbing device (T_1) was evaluated based on ergonomical parameters and ergo refinements were carried out. The inclination of upper frame of climbing device is increased (T_1) with respect to the horizontal, while moving towards the top of the tree. As a result, the centre of gravity of the user moves towards outside of the body making him feel insecure and unstable. The upper frame of coconut tree climbing device was suitably modified to avoid downward inclination such that ergo refined device (T_2) improves the safety and ease of operation. The ergo refined coconut tree climbing device (T_2) enhanced the comfort and safety of male subjects with 7.8, 12.2, 10.7 and 20.5% reduction in heart rate, energy expenditure, overall discomfort rating and body part discomfort score, respectively and 2.6 and 4.1% increase in overall safety and ease of operation rating respectively when compared to T_1. The ergo refined coconut tree climbing device resulted in 20.6% savings in cost and 11.8% savings in time of climbing and harvesting coconut when compared with T_1 model.

Key words: Coconut tree, climbing device, ergo-refinements.

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INTRODUCTION

Coconut (*Cocos nucifera* L.) palm is an important cash crop in India. India is the third largest producer of coconut in the world. Coconut is grown in an area of about 18.7 million ha with a productivity of 5718 nuts per hectare in India (National Horticulture Board, 2011). Generally, skilled workers climb to harvest the coconuts from the tree without any safety device. The coconut trees are very tall and injuries associated with coconut tree climbing, particularly falling from coconut trees is common in coconut plantations in India. The workers employed for climbing coconut tree suffer musculoskeletal disorders than any other type of injury or illness. With sufficient attention to the larger goals of whatever work is underway, investments in ergonomics can often pay for themselves many times over. George et al. (2012) reported that a total of 35.5% (78 cases out of 220 climbers) fell down from coconut trees while doing their job. A 7.9% (19/240) of the tree climbers in the study area withdrew from their traditional profession and remained unemployed. Among them, only 5.3% (1/19) stopped climbing trees due to health problems and 94.7% (18/19) withdrew because of casualties that happened

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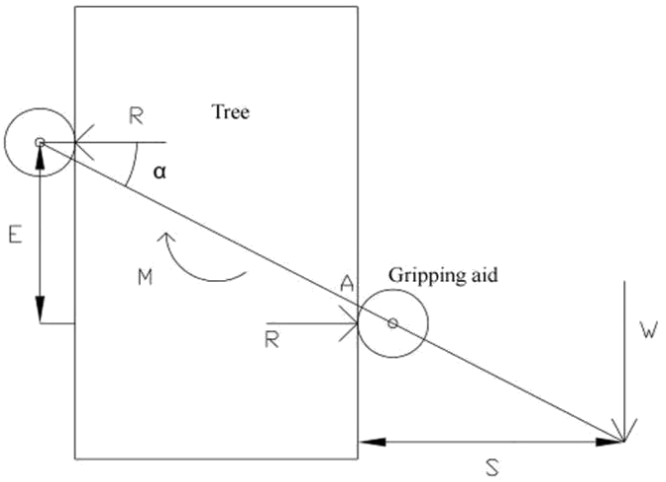


Figure 1. Gripping mechanism of tree climbing device.

during their occupation. Joseph (2006) developed a coconut-climbing device having two frames (left and right). Each frame was having flexible adjustable encircling iron rope mounted around a tree and tree gripping rubber pad. The two main frames were fitted on the tree side by side enabling the operator to lift the frames conveniently using the sliding member.

Laborde (2006) developed a climbing tree stand apparatus with upper and lower platforms that were independently movable up the tree from under alternatively sitting and standing on one or the other of the platforms. Mohanty et al. (2008) investigated that the comparative study on the ergonomics of farm women in pedal threshing with single and double operators suggest modifications for further reduction of human drudgery. Thiyagarajan et al. (2013) conducted ergonomics study on different sugarcane harvesting knives and improvement carried out among one knife which having minimum physiological cost. There is no device available with safety features and ergonomically designed. Keeping the aforementioned facts in view, the simple device was fabricated with safe and easy to use device for climbing coconut palms, which could even be operated by an unskilled person.

MATERIALS AND METHODS

The developed tree climbing device must ensure the following requirements. It should withstand enough loads exerted by climber. It should accommodate all kinds of climber. It should provide effective gripping over a wide range of tree diameters. It should conform to the shape of the tree trunk as much as possible for effective gripping. It should distribute the gripping forces uniformly over the tree surface to prevent damage to the tree surface and to prevent wear and tear of the gripping aids. It should grip the tree securely without any possibility of accidental failure. The climbing device was working as first class lever type principle. The important parameters that are associated with the design of tree climbing devices are crop parameter (tree trunk diameter) and climbing device parameter (anthropometric data of climber).

Crop parameter

Fifty tall coconut varieties were selected at random in a 23 year old coconut farm located at Negamam village (10.7333°N 77.1°E), Pollachi Taluk, Coimbatore district. The girth of these fifty trees was measured at three levels of height detailed as follows:

i) Height of coconut tree at 1 m above ground level (H_1);
ii) Height of coconut tree at 1 m below the bottom most frond level (H_2);
iii) Height of coconut tree at middle portion (H_3).

Since the cross section of the trunk is circular, the cross sectional diameter of the coconut trees were calculated.

Climbing device parameters

Gripping aid

Proper selection of material for gripping aids of the tree climbing device is a crucial factor as it influences the weight of the device, the flexibility and resistance to wear and tear. The gripping mechanism of tree climbing device is shown in Figure 1. Let, A - Point of contact of gripping aid with trunk, α - the inclination of frame with respect to horizontal, W - the load due to weight of climber on the frame, S - horizontal distance between A and point of action of CG (W) of climber, R - reaction force exerted by tree, E - vertical distance between the centres of gripping aids, μ - coefficient of friction of surface of trunk. Taking the moment about A,

$$W \times S = R \times E \quad (1)$$

For stability of frame without slipping, the frictional force experienced by the gripping aids should be more than the vertical component of weight of climber (W):

$$2\,R \times \mu > W \quad (2)$$

Anthropometric criteria for the design of tree climbing device

Anthropometry is the measurement of physical features of body including linear dimension, clearance, reach, posture, weight and volume. The following anthropometric parameters relevant to the development of tree climbing devices of Tamil Nadu agricultural workers were taken from the anthropometric data bank of agricultural workers of Tamil Nadu (All India Coordinated Research project on Human Engineering and Safety in Agriculture, 2000) and the values are furnished in Table 1.

Construction of climbing device

The device (T_1) is constructed of two sections which include upper and lower frames. These frames are independently movable and positionable along the coconut tree trunk. The upper frame member is a tubular frame work consisting of a rigid base section and an adjustable tree gripping section. The rigid base section carries a seating arrangement for accommodating the user, front support rail, cross rear rail and side rails. The user can sit comfortably facing the tree and receive support from the cross rear rail and the side rails. The seat is a flexible sagging type made of rexin fabric attached through loops between the rear and front cross rails of the frame.

Table 1. Anthropometric criteria for the design of tree climbing device.

S/N	Dimensions	Mean	SD	5th percentile value	95th percentile value
i	Age (years)	35.92	10.55	18.56	53.28
ii	Weight (kg)	56.14	9.69	40.21	72.08
iii	Trochanteric height	84.60	5.15	75.60	92.55
iv	Knee height sitting	47.41	3.16	42.21	52.61
v	Buttock to knee length (cm)	53.97	2.64	49.62	58.32
vi	Hip breadth sitting (cm)	29.97	3.147	24.79	35.13
vii	Functional leg length (cm)	101.39	7.14	89.65	113.13
viii	Grip diameter (inside) (cm)	5.02	0.75	3.79	6.25
ix	Heel breadth (cm)	5.51	2.38	1.60	9.43
x	Foot breadth (cm)	8.79	0.73	7.59	9.99
Xi	Lateral malleolus height (cm)	6.81	0.377	5.54	8.07

The tree gripping section consists of gripping aids to engage it on three points on the circumference of the tree. The gripping aid is a rubber bush inserted into a tubular square bar. The gripping section has three members which form a triangular throat that encompasses the upright coconut tree trunk, thereby permitting the upper frame member to be fixed to the tree. One of the removable gripping members is attached to the extendable arm and the other two are attached in "V' shape to the front support bar of the seating frame. The spacing between the gripping members is adjustable with the help of extendable arm to suit the girth of the coconut tree.

The lower frame member is also a tubular frame work consisting of a rigid base section and a tree gripping section similar to upper frame member except that the rigid base section is located adjacent to the tree trunk to support the weight of the user when the upper frame is repositioned on coconut tree. The rigid base section carries a pair of parallel tubular bar with rubber bushes for the user to insert his feet and lift the unit. Cushioning material is also provided around the rubber bushes for sophisticated purpose of user feet. The upper and lower frame members are connected with canvass belt to prevent them from slipping down the tree trunk. Handles provided on the side rails of the upper frame enable the user to lift the unit during ascending or descending the tree. After reaching the coconut tree top, the unit can be fitted to one of the front with the help of hook so that the user can get into the crown of tree for harvesting coconuts. The spacing of the gripping members is set initially to engage both the upper and lower frames with the outermost ends such that the inclination of the seat and foot rest being horizontal or parallel to the ground. To ascend the coconut tree, the user places his feet on the lower frame member. The user then rests his weight on the seating section of the upper frame while using his feet and legs to pull the lower frame upward. The user then stands by resting his feet on the lower frame and using his hands raises the upper frame to waist high position. The user then sits and again raises the lower frame with his feet and legs.

The view of the climbing device (T_1) is shown in Figure 2. The various physical parameter of developed tree climbing device (T_1) is furnished in Table 2. The operational view of developed tree climbing devices (T_1) is shown in Figure 3.

Centre of gravity (CG)

Mass of all bodies is equally distributed through their CGs. Location of the whole body centre of gravity is the resultant of the location of the segmental centers of gravity in the space. Determination of whole body centre of gravity of a coconut tree climber subject helps to understand the stability of the whole body while adapting the particular posture during climbing with a tree climbing device. The centre of gravity of a coconut tree climber subject was measured by segmental method (Hamil and Knutzen, 1995). The inclination of tree climbing device was calculated with various diameter of tree with various adjustable distances.

Inclination of tree climbing device

The inclination of tree climbing device was calculated using the following Equation 4. θ - Inclination of tree climbing device with respect to horizontal (°); X - diameter of the tree trunk (cm); Y - distance between the two gripping aids in throat area (cm):

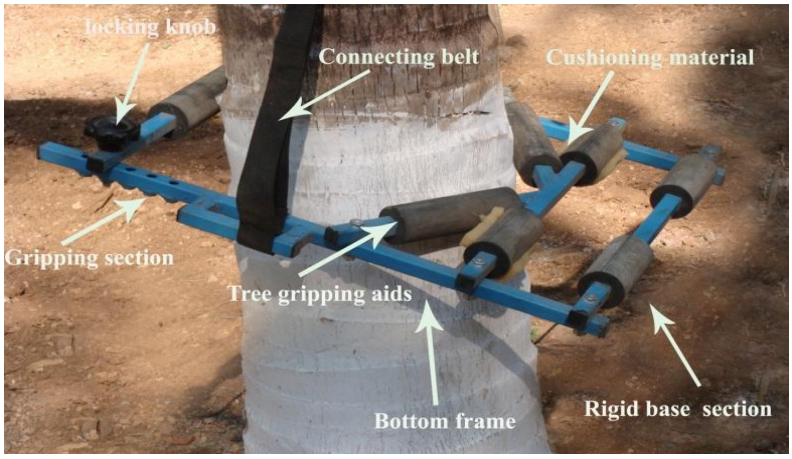
$$\theta = \tan^{-1}(Y/X) \quad (3)$$

Ergonomic evaluation

The developed coconut tree climbing devices was evaluated with twelve male coconut plantation workers. The subjects were screened for normal health through medical investigations. The age, weight and height of the selected male subjects were 32 ± 2.6 years, 58.8 ± 4.5 kg and 165.5 ±.6.8 cm respectively. The selected twelve male subjects were calibrated in the laboratory by indirect assessment of oxygen uptake. Ergonomic evaluation of the selected coconut tree climbing practices was conducted for assessing the suitability of the user with respect to comfort, safety and ease of operation. The evaluation was carried out with the twelve selected subjects in terms of heart rate (HR), oxygen consumption rate (OCR), energy cost of operation (ECR), acceptable work load (AWL), limit of continuous performance (LCP), over all discomfort rating (ODR), over all safety rating (OSR), over all ease of operation rating (OER) and body part discomfort score (BPDS). The heart rate data was recorded using computerized heart rate monitor (Polar S 810i).

From the down loaded data mean values of heart rate, oxygen consumption rate and the energy expenditure rate for all the subjects were computed. The energy cost of operation was graded as per the young Indian male workers given in ICMR report (Sen, 1969). The acceptable workload (AWL) for Indian workers was the work consuming 35% of VO_2 max (Saha et al., 1979). To ascertain whether all the selected coconut tree climbing practices were within the acceptable workload (AWL), the oxygen consumption rate in terms of VO_2 max was computed. To have a meaningful comparison of physiological responses, work pulse (ΔH) values (increase over resting values) were calculated. The mean values of work pulse for coconut tree climbing operation were compared with

(a)



(b)

Figure 2. View of upper and lower frame of the climbing device (T_1). a) Upper frame, b) Lower frame.

Table 2. Specification of developed coconut tree climbing device (T_1).

S/N	Particulars	Values
i	Size of the upper frame (cm)	106 × 51
ii	Size of the lower frame (cm)	62 × 51
iii	Size of the rigid base section in upper frame (L × B) (cm)	54 × 51
iv	Size of tree gripping section (L × B) (cm)	47 × 51
v	Number of cross rail in upper frame	5
vi	Number of cross rail in lower frame	4
vii	Diameter of locking knob gripping section (cm)	6
viii	Diameter of rubber gripping bush (cm)	5
ix	Length of rubber gripping bush in inclined rail of tree gripping section (cm)	15
x	Length of rubber gripping bush in cross rail of tree gripping section (cm)	20
xi	Gripping diameter of tree trunk in extendable arm (cm)	25 - 35 adjustable in 5 steps
xii	Number of bushes in upper frame	3
xiii	Number of bushes in lower frame	7
xiv	Length of safety strap (cm)	110
xv	Width of the belt (cm)	5
xvi	Weight of the upper frame (kg)	6.7
xvii	Weight of the lower frame (kg)	6.1
xviii	Width of canvas belt (cm)	5

Figure 3. The operational view of developed tree climbing devices (T_1).

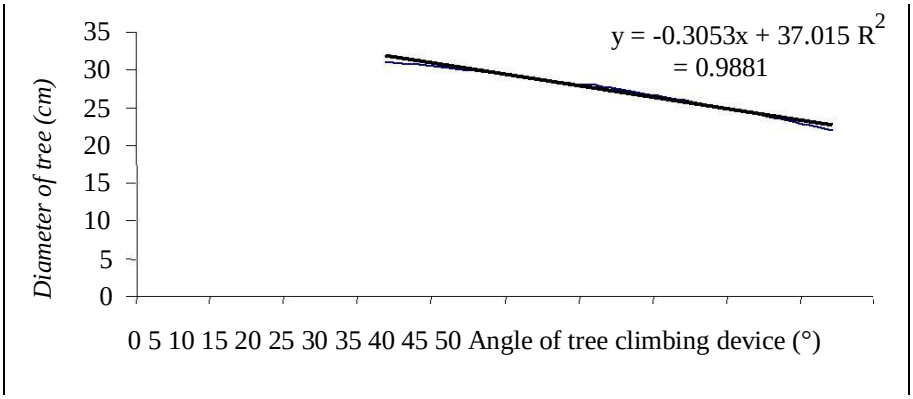


Figure 4. Effect of tree diameter on the inclination of tree climbing device with 32.5 cm adjustable distance.

the acceptable work pulse values of 40 beats min^{-1} as limit of continuous performance. For the assessment of overall discomfort rating (ODR) and localized discomfort (BPDS), a 10 - point psychophysical rating scale was used which is an adoption of Corlett and Bishop (1976) technique. The work time was fixed as 60 min of operation. At the end of each trial with the selected coconut tree climbing practice, the subject was asked to indicate their ODR and BPDS level on the 10-point rating scale.

RESULTS AND DISCUSSION

The diameter of coconut tree is important morphological character that influences the performance of tree climbing device. Adjustable distance of removable gripping aids of coconut tree climbing device was fixed based on the diameter of the tree. From the collected data it was observed that, the minimum and maximum adjustable distance was 22.5 and 32.5 cm, respectively. Hence, the tree triangular throat of tree climbing device accommodated to tree trunk.

Centre of gravity of operator's body posture

The centre of gravity of tree climber was located with different inclination of tree climbing device in lab condition. The inclination of tree climbing device was calculated with various diameter of tree. The inclination of tree climbing device is influenced by the diameter of tree at various adjustable distances. From that analysis it was inferred that the minimum and maximum inclination of tree climbing device at maximum adjustable distance of 32.5 cm is 16 and 47°, respectively with the horizontal. The inclination of tree climbing device is shown in Figure 4.

Centre of gravity

The centre of gravity of the operator while climbing coconut tree using the tree climbing device of different inclinations of the upper frame was calculated. The

Table 3. The anthropometric criteria of ergo refined coconut tree climbing device.

S/N	Anthropometric dimensions	Corresponding work space dimensions in coconut tree climbing device	Percentile value chosen	Ergo refined unit dimension
i	Buttock to knee length (cm)	Seat centre to tree	58.32(95th)	41.5
ii	Hip breadth sitting (cm)	Sitting frame breadth	35.13(95th)	43
iii	Functional leg length (cm)	Length of the connecting belt	89.65 (5th)	110
iv	Grip diameter (inside) (cm)	Width of handle	3.79(5th)	1
v	Heel breadth (cm)	Length of foot rest (rear) in lower frame	9.43 (95th)	10
vi	Foot breadth (cm)	Length of foot rest (front) in lower frame	9.99 (95th)	10
vii	Lateral malleolus height (cm)	Gap between two foot rest of lower frame	8.07 (95th)	9

Figure 5. The ergo refined tree climbing device (T_2).

centre of gravity of tree climber shifted outside of the body at more than 40° inclination of tree climbing device. Hence, the safe inclination of tree climbing device is less than 40° with horizontal. While operator moves towards top of the tree, with increase in height of tree, the diameter of coconut tree trunk decreases. The inclination of upper frame of coconut tree climbing device is increased with respective horizontal. As a result the centre of gravity of the user shifts outside of the body (Grimshaw and Burden, 2007) and the user feels insecure and unstable. The upper frame of coconut tree climbing device was suitably modified to avoid downward inclination.

Ergo refined tree climbing device

To achieve better efficiency of performance with more human comfort, it is necessary to modify the operator's work place in the coconut tree climber device keeping anthropometric suitability. To suit the convenience of the tree climber, the values of pertinent anthropometric criteria of ergo refined coconut tree climbing device dimensions of agricultural workers of Tamil Nadu considered are furnished in Table 3. The tree holding section with triangular gripping aids was replaced with telescopic 'I' section and 'U' shaped gripping member. The 'U' shaped member with single gripping aid encircles the girth of coconut tree aiding in gripping the tree trunk rigidly. Initially the upper frame is fitted in an inclined position towards the trunk of the tree. As the user ascends the tree with decrease in diameter, the upper frame becomes exactly horizontal and parallel to the ground. This prevents shifting of center gravity of user to unsafe position and ensures stability. Back rest was also provided for user safety purpose. The ergo refined tree climbing device (T_2) is shown in Figure 5. The centre of gravity of T_1 and T_2 trees climbing device is shown in Figure 6.

Evaluation of ergonomic parameters

Ergonomic evaluation was carried out on both T_1 and T_2 model. The trials were conducted between 7.00 AM to 5.00 PM with twelve plantation workers. The temperature

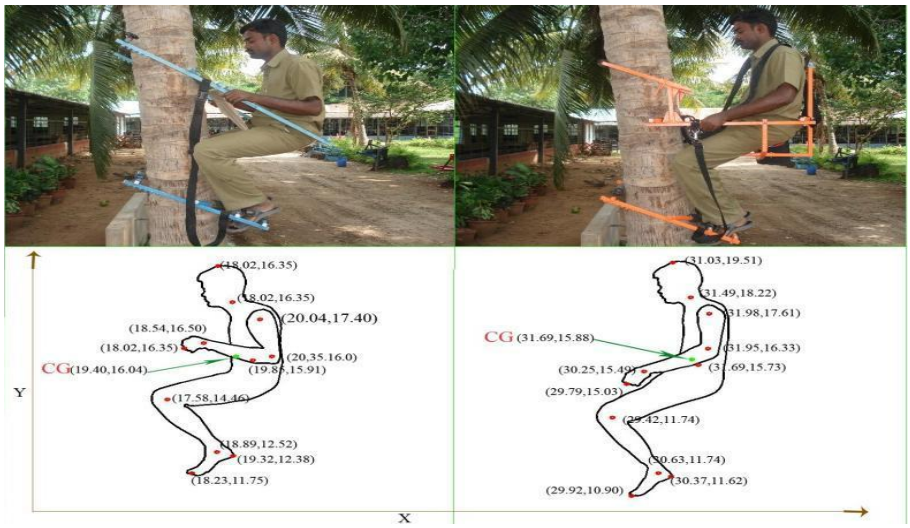


Figure 6. The whole body CG of T_1 and T_2 model located by segmental method.

Table 4. Ergonomic parameters of T_1 and T_2 models.

S/N	Parameters	T_2 model	T_1 model
i	Heart rate (beats min^{-1})	138.1	127.3
ii	Energy expenditure (kJ min^{-1})	28.6	25.1
iii	Work pulse (ΔH) (beats min^{-1})	51.8	43.8
iv	Grading of energy cost	Heavy	Heavy
v	ODR	5.6	5.0
vi	Over all safety rating (OSR)	6.9	6.4
vii	Ease of operation rating (OER)	5.9	3.8
viii	BPDS	41	34

Table 5. Cost economic of coconut tree climbing and harvesting.

S/N	Parameters	Coconut tree climbing device	
		T_2	T_1
i	Harvesting capacity (number of coconuts hr^{-1})	56	44
ii	Cost of harvesting (Rs. nut^{-1})	0.75	0.95
iii	Savings in cost of harvesting coconut with ergo refined unit (%)		20.6
iv	Total number of trees per ha	178	178
v	Total time required for climbing and harvesting coconut per ha hr^{-1}	13.35	15.13
vi	Time required for climbing and harvesting coconut in one tree (min)	4.5	5.1
vii	Savings in time of harvesting coconut with ergo refined unit (%)		11.8

and relative humidity varied from 28 to 32°C and 56 to 65% respectively during the period of evaluation. The comparison of T_1 and T_2 models values are furnished in Table 4. Among the two models of coconut tree climbers, T_2 model recorded the lower value of physiological cost and reduced discomfort and higher values of safety and ease of operation when compared to T_1. The energy expenditure in terms of VO_2 max for T_1 and T_2 models are shown in Figure 6.

Costs and benefits analysis

Ergonomics-costs and benefits

The effectiveness of harvesting coconut using ergo refined coconut tree climbing device in terms of savings in cost and time is compared with initial coconut tree climbing device. The values are furnished in Table 5. The ergo refined (T_2) device resulted in 20.6% saving in cost

and 11.8% saving in time of climbing and harvesting coconut when compared with T_1 model.

Conclusion

Among the developed two models of coconut tree climbing devices, T_2 model recorded the lower value of physiological cost and reduced discomfort and higher values of safety and ease of operation when compared to T_1 model. The ergo refined coconut tree climbing device (T_2) enhanced the comfort and safety of male subjects with 8.5, 14.2, 14.2, 14.2, 18.3, 11.4 and 21.3% reduction in heart rate, oxygen consumption, energy expenditure, acceptable work load, limit of continuous performance, overall discomfort rating and body part discomfort score respectively and 2.6 and 4.1% increase in overall safety and ease of operation rating respectively when compared to T_1 model.

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