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ACKNOWLEDGEMENTS. This study was supported by the National Natural Science Foundation of China (Grant No. 41701045) and Opening Fund of Key Laboratory of Ecohydrology of Inland River Basin, Chinese Academy of Sciences, Project No. KLEIRB-ZS-16-05. We thank the anonymous reviewers for their constructive comments which helped improve the manuscript.

Received 7 December 2017; revised accepted 30 August 2018

doi: 10.18520/cs/v116/i1/121-127

Assessment of ergonomic parameters of coconut climbing devices for women

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At present there are different models of coconut climbing devices available in the market. The safety and efficiency aspects of coconut climbing devices are not being studied for women. Therefore, a study was undertaken to evaluate the existing models of five coconut climbing devices, 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 on ergonomic basis for women operators. Minimum heart rate and energy expenditure was observed for KAU coconut palm climber than other models. The subjects felt less safety in operating TNAU model and standing type (Chemberi model). Sit and climb type (TNAU model) was found difficult to operate compared to other devices. On basis of these results it was found that KAU coconut palm climber was more suitable and ergonomically comfortable for the women operators.

Keywords: Coconut climbing devices, ergonomics, heart rate, energy expenditure, women workers.

KERALA derives its name from the word 'Kera' which refers to coconut tree, the most important plantation crop of the state. The farming sector of Kerala has problems like shortage of labour, lack of trained labour and high cost of available labour. Mechanization is considered a remedy to the growing labour scarcity and uneconomic nature of farming. In the case of coconut cultivation, harvesting the nuts and plant protection are major problems. Majority of coconuts are harvested by climbing the palm and cutting bunches down by knife. This process may seem simple but it is quite dangerous and time-consuming. Coconut palms are very tall; any fall from the top of the palm can result in severe injury, even death. Due to the strenuous nature of work and risk involved, professional coconut climbers are now very few in number and timely harvest of the nuts forms a severe constraint in coconut farming. In response, there is a genuine need to develop safe and efficient devices to facilitate easy climbing. Mechanization is the available option and several coconut climbing devices have been developed that help climbers.

Women play a vital role in agriculture. According to the 2011 census, women constitute 37% of the total work

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force of the country and this is expected to rise to 45% by 2020. In this context, development of women-friendly tools and machines assumes significance[1]. But there are very few machines to ease women's manual labour. The machines available are not popularized and field-tested.

Agricultural ergonomics is a branch of science with high relevance to all activities of farming. An application of this discipline in agriculture can help in improving the efficiency of human labour without adversely affecting their health and safety. Ergonomic evaluation of farm tools will result in achieving better harmony and coordination between the tools and the worker[2]. This harmony can result in reduction of fatigue, discomfort and enhance the productivity of labour involved. Studies on ergonomic evaluation of tools and equipment can hence provide data for further improvement in design to suit human labour operating the same, resulting in better safety, more output and less drudgery.

At present there are different models of coconut climbing devices available in the market. However safety and efficiency aspects of climbing devices have not been studied for women and need to be comparatively evaluated. Hence a study was undertaken to evaluate the existing models of coconut climbing devices to select the best coconut climber suited to homesteads of Kerala for more output and safety of women operators. The selected models are 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.

The sit-and-climb type model (TNAU model) was developed in Tamil Nadu Agricultural University (Coimbatore) during 2006. The device comprises an upper frame and a lower frame which are made up of mild steel pipes with rectangular cross-section. The upper frame is divided as fixed section and adjustable section. The fixed section is provided with a seating arrangement in which the operator can sit and climb the palm. The adjustable section has three members in which two are attached in V-shaped form and the other is removable with a provision to fix on the frame depending upon the girth of the palm. This section is provided with rubber bushes for proper gripping on the trunk of the palm. The lower frame is similar to the upper frame except that the fixed section is located near the trunk of the palm and has provision for holding the feet. The portion for holding the feet is provided with rubber bushes with cushioning material to avoid abrasions on the feet. Both frames are connected by an adjustable canvas belt which prevents the operator from slipping down the trunk. The upper frame is provided with handles to lift the unit. The operator can ascend or descend the tree by moving the upper and lower frames alternatively. By standing on the lower frame, the upper frame can be moved up or down along the trunk. Similarly by sitting on the upper frame, the lower frame can be moved up or down. Hooks are provided in the climber to fix the unit at the top of the coconut palm.

Standing type (Chemberi model) was originally developed by M. J. Joseph, a farmer from Chemberi village of Kannur district in Kerala. At present this device is available at various government agencies in Kerala. The device has two frames (left and right). The main frame is made of 12 mm diameter mild steel rod. Each frame comprises flexible adjustable encircling iron rope (8 mm diameter, length 1060 mm) mounted around a palm and palm gripping semi-circular pad made of worn out tyre rubber pad fitted against the palm trunk. One end of the iron rope is attached to the rubber pad and the other end is placed on adjusting holes to changing rope length according to girth of the palm. The adjusting holes comprise bolts and wing nuts to fasten the ropes. The main frames having the foot rest comprise a safety strap to prevent accidental slip during engagement with the climber's feet while ascending and descending the palm. The two main frames are fitted on the palm nearby, facilitating the operator to lift the frames easily using the sliding member.

Before climbing, the climber fixes the climbing device, both left and right units, to the palm with the help of wire rope provided. The climber holds the handles of both units and climbs on by keeping both legs in the foot rest provided. Then the right unit of the device is lifted by hand to about 30 to 40 cm, after loosening the rope with the help of the right leg. After lifting the unit, the foot is pressed downwards to hold the coconut palm firmly by the rope and pad provided. The operation is repeated by the left unit without releasing the body weight from the left unit. The operation is repeated to reach the required height. For climbing down, the reverse operation will be followed, i.e. release the wire rope of the left unit by lifting the footrest. The climber brings down the left unit by 30–40 cm and then puts the body weight on the left footrest followed by the right unit. While climbing, care should be taken not to overlap the ropes of the climbing units leading to jamming of the device.

The KAU coconut palm climbing device was developed by Kelappaji College of Agricultural Engineering and Technology (Tavanur, Malappuram), Kerala Agricultural University (Thrissur) with modifications over the TNAU model. The material of construction of the upper frame has been changed to GI pipe and lower frame to aluminium to reduce the total weight of the equipment thus making it more easy to use. The palm gripping portion of both upper and lower frames has been changed from a square frame to a 'U' frame. This 'U' frame helped to reduce the clearance space between the coconut trunk and equipment at all locations, thus reducing the sway of the equipment. The rubber bush for gripping is provided in the middle of the U frame. Safety lock pins have been added to ensure better safety. Specially

designed footwear is also introduced to the lower frame that is easier to use and it is one of the major advantages over other models.

The Kerasureksha coconut climbing device was developed at the Agricultural Research Station, Kerala Agricultural University (Mannuthy, Thrissur, Kerala). This simple device consists of an upper frame, the seating unit, lower frame and the pedal unit. The upper and lower frames are freely movable and can be positioned along the trunk of the coconut tree. The upper frame is made up of stainless steel and comprises a fixed base section and an adjustable palm gripping section. The fixed base section holds a seating unit for accommodating the operator, side rail for hand support on one side and a V-shaped portion with rubber blocks. The seating structure is chair like and is linked to the V-shaped portion. Hand support on one side provides safety and easier entry and exit for the climber from the set-up.

The palm gripping section consists of a V-section with rubber blocks and a locking mechanism. The locking mechanism in this equipment is rather simple. Lynch pins are used to lock the palm gripping section with the rigid sitting section. These pins are passed through slots after matching the slots in sitting and gripping sections. These pins enable easy harnessing and the pin slot can be chosen as per the coconut trunk diameter. The V-section of the palm gripping section along with the V-portion of the upper sitting frame forms the gripping mechanism. The load of the sitting climber pushes the rubber block of the sitting frame towards the trunk while it simultaneously pulls the rubber blocks of the gripping frame towards the trunk, thus providing a firm grip.

The lower frame is also made up of stainless steel and comprises a fixed base section and an adjustable palm gripping section except that the fixed section is located near the trunk of the palm. The fixed base section has a pedal-like section and a V-shaped portion with rubber blocks similar to that of the upper frame. The palm gripping section of the lower frame has a V-shaped gripping part and a locking mechanism. These operate exactly the same way as the upper frame to provide grip on the coconut trunk. The upper and lower frames are connected by an adjustable belt which holds back the operator from slipping down the trunk.

The CPCRI model coconut climbing device is developed at the Central Plantation Crop Research Institute (Kasaragod, Kerala). This model is almost the same as that of Chemberi model. The institute has done a small modification to the standing type (Chemberi model) by incorporating a safety device for safe climbing of the operator. For that, the main frame of the coconut climber is provided with two metal rings at the bottom of the handle of the right leg unit of the climbing machine. A steel rope of 6 mm diameter is provided with hooks at both ends. The steel rope is taken through rings and around the palm to make a tie and the other end is connected to the belt worn by the operator. The steel rope moves up and down with the climbing device while in use. In case of any accidental slipping down of the operator from the tree, the tie tightens around the trunk and prevents the operator from falling further.

An anthropometric survey was conducted to select the subjects for the study. The pertinent anthropometric dimensions of women labourers with reference to the dimensions and positions of the functional components of coconut climbers were identified. Thirty five different body dimensions useful for the design or redesign of coconut climbers selected for the study were recorded by following standard anthropometric procedure. The standard performa developed by the All India Coordinated Research Project on Ergonomics and Safety in Agriculture was used for collecting anthropometric data. A sample of 30 subjects was selected from the northern, central and southern zones of Kerala. Hence anthropometric data of a total of 90 women were collected from three zones. In order to measure the various body dimensions of the subjects, an integrated composite anthropometer, digital hand grip dynamometer, conical shape device for measuring internal grip diameter and medical balance were used. The subjects were briefed about the survey beforehand demonstrating the measurement procedure, in order to ensure their full cooperation.

Five female subjects based on statistical analysis of the anthropometric data were selected for the study so that the selected subjects were a true representative with respect to anthropometric dimensions. Maximum strength or energy can be anticipated from the age group of 25 to 35 years[3]. Hence five subjects well trained in the operation of coconut climbers in the ages between 20 and 40 years were chosen. Selected subjects were bio-clinically tested and had normal health and were medically fit for the study.

All the selected subjects were calibrated in the laboratory to determine the relationship between heart rate and oxygen consumption before conducting the actual field experiment. This relationship is used to assess the energy expenditure indirectly. Both heart rate and oxygen consumption have to be recorded simultaneously under different sub-maximal workloads in the laboratory[4]. Since the relationship between the two variables is linear, oxygen consumption of the subject can be predicted from the calibration chart corresponding to the measured heart rate during work[5].

During calibration, the subjects pedalled a standard bi-cycle ergometer at predetermined speed. Both heart rate and oxygen uptake was measured simultaneously to obtain a relationship between heart rate and oxygen consumption while pedalling the bicycle ergometer. The workload of the subjects was increased gradually by increasing the resistance to the pedals using the tension knob until the subject was exhausted. Oxygen consumption was measured using Benedict-Roth recording

spirometer and the heart rate using polar heart rate monitor[6]. A calibration chart was plotted with heart rate as the ordinate and the oxygen consumption as the abscissa for the selected five subjects. The calibration chart of subjects is presented in Figure 1. It is observed that the relationship between the heart rate and oxygen consumption of the subjects was found to be linear for all the subjects[5].

The ergonomic evaluation was carried out at Farming System Research Station, Sadanandapuram (Kollam district, Kerala). The working of coconut climbers was checked before starting the experiment. A thorough training was given to the subjects, who already had experience in coconut climbing, to familiarize with the coconut climbing devices for a week until they got used to them. A 30 min rest was recommended for the subjects before the start of each trial. The heart rate of the subject was measured continuously till they showed normal and steady heart rate. After reaching the normal heart rate, the subjects were asked to operate the climber. The heart rate was recorded using polar heart rate monitor during operation of each model of coconut climber.

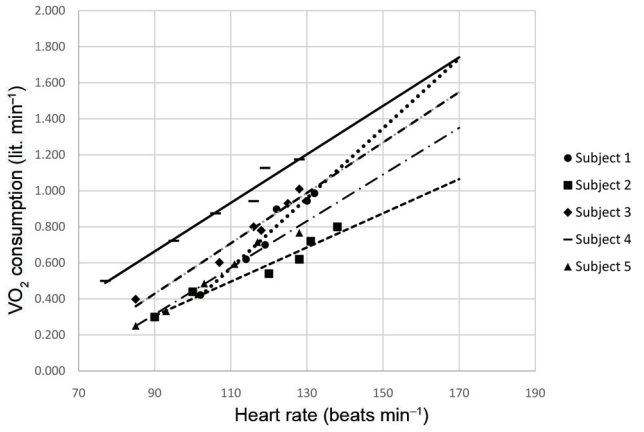

Figure 1. Relationship between oxygen uptake and heart rate.

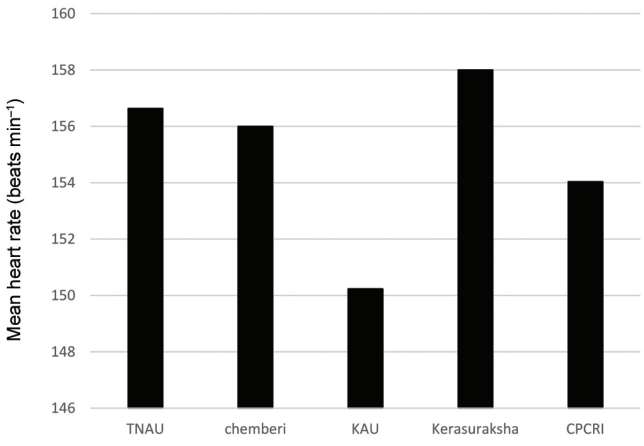

Figure 2. Mean heart rate of female subjects during coconut climbing.

From the mean values of heart rate (HR) recorded during experiment, the corresponding values of oxygen consumption (VO_2) of the subjects were predicted from the calibration curves of the subjects. The energy expenditure while operating coconut climbers was computed by multiplying the value of oxygen consumption (mean of the values of five subjects) by the calorific value of oxygen (20.88 kJ l^{-1})[7].

The mean heart rate of subjects during operation of selected coconut climbers are shown in Figure 2. It is quite clear that maximum heart rate was observed in Kerasureksha coconut climbing device with a value of 158 beats min^{-1} followed by TNAU model coconut climbing device with a value of 156.33 beats min^{-1}. It is further observed that subjects showed minimum heart rate while operating KAU coconut palm climbing device with a value of 150.23 beats min^{-1}.

Statistical analysis was done to find the effects of selected coconut climbing devices and their interaction effect on subjects' heart rate and energy expenditure. The data collected were analysed statistically as 2 × 3 factorial experiments. IBM SPSS 24.0 statistical software was used to analyse the data. Analysis of variance (ANOVA) with the General Linear Model (GLM) procedure from IBM SPSS 24.0 software was used. Multivariate test with POST-HOC (BUTKEY) analysis was used to compare the significant differences among mean of the treatments at 5% level of probability and relationship between subgroups of sampled data.

Variation of heart rate and energy expenditure for selected operations were statistically analysed (Tables 1 and 2). It is quite evident that all female subjects except subject 2 showed significantly differed heart rate on different coconut climbing devices and all the female subjects showed minimum heart rate while operating KAU coconut palm climbing device. Hence it was concluded that female subjects showed differed heart rate while operating different models of coconut climbing devices with a significant difference.

All the subjects except subject 2 showed significantly differed energy expenditure while operating different models of coconut climbing devices. Energy cost recorded was significantly lower in the KAU coconut climbing device.

The workload should be expressed as a percentage of the maximum aerobic capacity of the individual. Thirty five per cent of maximum aerobic capacity was taken as the acceptable workload (AWL) for Indian workers[8]. Maximum oxygen uptake (VO_2 max) was predicted from the relationship between heart rate and oxygen consumption. Maximum heart rate of each operator was determined by the relationship as follows[9]

Maximum heart rate (beats min^{-1})

$$= 200 - 0.65 \times \text{age in years}.$$

Table 1. Variation of average heart rate (beats min^{-1}) while operating different models

Coconut climbers	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
TNAU model	162.667[a]	169.333[a]	142.000[b]	162.000[c]	147.167[c]
Chemberi model	174.333[b]	172.000[a]	140.667[ab]	156.000[ab]	137.000[ab]
KAU Model	162.333[a]	165.333[a]	135.167[a]	152.667[a]	135.333[a]
Kerasureksha model	168.167[ab]	171.500[a]	140.333[ab]	159.500[bc]	150.500[c]
CPCRI model	163.667[a]	168.667[a]	143.167[b]	153.000[a]	141.667[b]

In column, mean values followed by the same letter do not differ significantly at $P = 0.05$ according to *post hoc* tests.

Table 2. Variation of average energy expenditure (kJ min^{-1}) while operating different models

Coconut climbers	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
TNAU	33.244[a]	22.155[a]	24.196[b]	34.224[c]	21.892[c]
Chemberi	37.970[c]	22.684[a]	23.806[ab]	32.533[ab]	19.153[ab]
KAU	33.109[a]	21.362[a]	22.198[a]	31.594[a]	18.704[a]
Kerasureksha	35.472[ab]	22.585[a]	23.709[ab]	33.520[bc]	22.789[c]
CPCRI	33.649[a]	22.023[a]	24.537[b]	31.687[a]	20.410[b]

In column, mean values followed by the same letter do not differ significantly at $P = 0.05$ according to *post hoc* tests.

The oxygen uptake corresponding to the computed maximum heart rate in the calibration chart gives the maximum aerobic capacity (VO_2 max)[10].

The oxygen consumption with respect to maximum aerobic capacity was calculated and given in Table 3. It is seen that all values were higher than that of the acceptable limit of 35%. Hence the selected coconut climbers could not be operated continuously for 8 h without taking rest[10]. The oxygen consumption in terms of VO_2 max was lowest for KAU coconut palm climbing device. The maximum VO_2 max is observed to be 79.74% for Kerasureksha coconut climbing device.

Postural discomfort was assessed using rating scales such as overall discomfort rating (ODR) and body part discomfort score (BPDS). Overall safety rating (OSR) and overall ease of operation rating (OER) were also assessed for each coconut climber. A ten-point psychophysical rating scale (0 – no discomfort, 10 – extreme discomfort) was used for rating the overall discomfort and a body map technique in which the body is divided into 27 regions was used for assessing the body part discomfort score (BPDS)[11]. For rating the safety of a coconut climber, a ten-point scale (0 – completely secure and no fear, 10 – totally insecure and extreme fear) was used. For rating the ease of operation, a ten-point scale (0 – very easy, 10 – extremely difficult) was used[12]. The scale for ODR, OSR and OER is given in Table 4.

The mean overall discomfort scores, overall safety and overall ease of operation rating rated by five subjects during operation of coconut climbing devices are given in Table 5. It is observed that female subjects experienced more discomfort rate for sit-and-climb type (TNAU model) with a score of 5.8 followed by CPCRI model coconut climbing device with a score of 4.6. The high discomfort score of sit-and-climb type (TNAU model) was because of its heavy weight. In the CPCRI model coconut climbing device, an additional jacket is provided to the machine which causes discomfort to the subject. The discomfort level of standing type (Chemberi model) and KAU coconut palm climbing device is comparatively less.

The subjects felt less safety in operating TNAU model and standing type (Chemberi model) with the same score of 5.2. The safety rating was comparatively less for KAU coconut palm climbing device and CPCRI model coconut climbing device for female subjects which indicated that these two models are comparatively safe during operation. Sit-and-climb type (TNAU model) was found difficult to operate compared to other devices with a score of 7.2. The rating on ease was found less for KAU coconut palm climbing device with a score of 2.8.

Body part discomfort score was maximum for sit-and-climb type (TNAU model) with a score of 35.7 while it was minimum for KAU coconut palm climbing device (26.4). In sit-and-climb type (TNAU model) and Kerasureksha coconut climbing device, the whole leg portion (lower frame) has to be lifted up by the front portion of the foot, that give subjects more pain in the foot with the skin being irritated. Also in the case of sit-and-climb type (TNAU model) the weight is too high and hence the lifting of the unit is difficult for female workers. Seat of sit-and-climb type (TNAU model) leads to back pain due to the lack of back supporting structure and caused rashes on the thigh portion because of the material of the seat. But on comparing with other models, KAU coconut palm climbing device was more comfortable for subjects

Table 3. Oxygen uptake in terms of VO_2 max in coconut climbing operation

Model	Mean VO_2	Oxygen uptake in terms of VO_2 max (%)	Acceptable workload (AWL) (35% of VO_2 max)
TNAU	1.30	78.37	>AWL
Chemberi	1.30	78.62	>AWL
KAU	1.23	74.30	>AWL
Kerasureksha	1.32	79.74	>AWL
CPCRI	1.27	76.41	>AWL

Table 4. Scale for overall discomfort rating (ODR), overall safety rating (OSR) and overall ease of operation rating (OER)

Levels	ODR	OSR	OER
0	No discomfort	Completely secure and no fear	Very easy
1			
2		Secure and meagre fear	Easy
3	Light discomfort		
4		Moderately secure and less fear	Less difficulty
5	Moderate discomfort		
6		Slightly secure and moderate fear	Difficult to operate
7	More than moderate		
8		Insecure and more fear	Very difficult
9	Very uncomfortable		
10	Extreme discomfort	Totally insecure and extreme fear	Extremely difficult

Table 5. Overall discomfort scores, overall safety and overall ease of operation of selected coconut climbing devices

Model		ODR	OSR	OER
TNAU	Score	5.8	5.2	7.2
	Scale	> Moderate discomfort	>Moderately secure and less fear	>Difficult to operate
Chemberi	Score	3	5.2	2.8
	Scale	Light discomfort	>Moderately secure and less fear	>Easy
KAU	Score	3	2.8	2.4
	Scale	Light discomfort	>Secure and meager fear	>Easy
Kerasureksha	Score	3.8	3.2	4
	Scale	>Light discomfort	>Secure and meager fear	Less difficulty
CPCRI	Score	4.6	2	4.4
	Scale	>Light discomfort	Secure and meager fear	>Less difficulty

because the specially designed shoes provided a good feel during operation. Similarly, in the case of Kerasureksha coconut climbing device the seating arrangement was more comfortable than other models. For Chemberi and CPCRI model coconut climbing device, the bending posture while stepping up and down of the lower portion of coconut climbing device caused discomfort and for CPCRI model the jacket made this problem all the more.

Ergonomic, comfort and safety aspects should be considered while designing all types of farm machinery including hand tools for reducing work load/drudgery and thereby increasing productivity of women who form a majority of agricultural workers in India. Female subjects showed differed heart rate while operating different models of coconut climbing devices with a significant difference. Minimum energy expenditure was observed for KAU coconut palm climber than other models. The oxygen consumption with respect to maximum aerobic capacity was also minimum for KAU coconut palm climber (74.30%) while it was maximum for Kerasureksha coconut climbing device with a value of 79.74%. The subjects felt less safety in operating TNAU model and standing type (Chemberi model) with the same score of 5.2.Sit and climb type (TNAU model) was found difficult to operate compared to other devices. KAU coconut palm climbing device was found more comfortable for women operators.

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Received 18 June 2018; accepted 26 August 2018

doi: 10.18520/cs/v116/i1/127-133