Evaluation of Physiological Cost and Subjective Assessment of existing Coconut Climbing devices

By

HAMEEDA BINDU VAHAB

2013-18-112

Department of Farm Power Machinery and Energy

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY TAVANUR - 679 573, MALAPPURAM KERALA, INDIA

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

Masters of Technology In Agricultural Engineering

Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

DEPARTMENT OF FARM POWER MACHINERY AND ENERGY
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
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ABSTRACT

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KERALA, INDIA

2015

DECLARATION

I hereby declare that this thesis entitled **"EVALUATION OF PHYSIOLOGICAL COST AND SUBJECTIVE ASSESSMENT OF EXISTING COCONUT CLIMBING DEVICES"** is a bonafide record of research work done by me during the course of academic programme in the Kerala Agricultural University and that the report has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Tavanur

Date:

Hameeda Bindu Vahab

2013-18-112

Dr. Bini Sam
Associate Professor
Department of Farm Power Machinery and Energy
Kelappaji College of Agricultural Engineering and Technology
Kerala Agricultural University
Tavanur, Malappuram, Kerala

Date:

CERTIFICATE

Certified that this thesis entitled **"EVALUATION OF PHYSIOLOGICAL COST AND SUBJECTIVE ASSESSMENT OF EXISTING COCONUT CLIMBING DEVICES"** is a bonafide record of research work done independently by **Hameeda Bindu Vahab (2013-18-112)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship, associateship to her.

Tavanur

Dr Bini Sam
Chairman
Advisory Committee

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Dedicated to

The Profession of

Agricultural Engineering

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF SYMBOLS AND ABBREVIATIONS

AWL	**-**	**Acceptable workload**
ARS	**-**	**Agricultural Research Station**
BPDS	**-**	**Body Part Discomfort Score**
beats min^{-1}	**-**	**Beats per minute**
CPCRI	**-**	**Central Plantation Crop Research instituite**
FSRS	**-**	**Farming Systems Research Station**
g	**-**	**Grams**
KAU	**-**	**Kerala Agricultural University**
KCAET	**-**	**Kelappaji College of Agicultural Engineering and Technology**
HR	**-**	**Heart rate**
k Cal	**-**	**Kilo Calories**
kJ min^{-1}	**-**	**Kilo Joule per minute lit**
min^{-1}	**-**	**Litre per minute**
LCP	**-**	**Limit of Continuous Performance**
min	**-**	**Minute**
ODR	**-**	**Overall Discomfort Rating**
OER	**-**	**Overall Ease of Operation Rating**
OSR	**-**	**Overall Safety Rating**
s	**-**	**Second**
TNAU	**-**	**Tamil Nadu Agricultural University**
VO_2	**-**	**Volume of Oxygen consumed**

Introduction

CHAPTER 1

INTRODUCTION

Kerala has it's own contribution in Indian agriculture economy. The net area under cultivation in Kerala during the year 2013-14 was 2.05 million ha, which occupies 52.78 per cent of the total area in the State. The area under coconut cultivation during 2013-14 was 0.81 million ha. Kerala provides about 70 per cent of Indian output of coconuts (Dept. of Economics and Statistics 2015, Kerala). Considering the area under cultivation of crops, coconut occupies the first place among them. Coconut provides a principal source of agricultural income in Kerala- from coir industry to coconut shell artifacts; coconuts bring much economic gains to Kerala. Kerala is actually named after the coconut tree with "Kera" meaning Coconut tree and "Alam" meaning land thus meaning "Land of Coconut Trees".

The farming sector of Kerala state is experiencing problems like shortage of labour in peak season, lack of trained labour, high cost of available labour and high cost of production. Mechanization is considered as a remedy to the growing labour scarcity and uneconomic nature of farming. Though there is an increased initial cost in operationalizing the machinery, effective mechanization contributes towards increase in profitability by achieving timeliness in operation and increasing quality of work in the longer run. In the case of coconut cultivation, harvesting of the nuts and plant protection works are major problems. Majority of coconuts are harvested by climbing the palm and cutting bunches down by knife. This process may seem to be simple but it is quite dangerous and time consuming. Normally skilled workers climb the palm to harvest the coconuts. Since coconut palms are very tall, any fall from the top of the palm can result in severe injury, even death. The climbers employed for climbing coconut palm suffer from musculoskeletal disorders which disable individuals at rates near or above those of traumatic, respiratory and dermatological injuries. Due to the strenuous nature of the work and risk involved professional coconut climbing devices are now very few in number and farmers are finding it difficult to harvest the nuts. In response, there is a genuine need to develop a device which is safe and efficient to facilitate easy climbing. Mechanization is the available option and several coconut climbing devices have been developed that helps climbers.

An ergonomically designed system should ensure efficiency, health and mental satisfaction of the humans interacting with machine and his surroundings. Ergonomics is often referred to as an external triangle between efficiency, comfort and health. However, not enough attention has been given to ergonomics in farming operations and in the design of agricultural equipment/ machinery.

In agriculture, the scope and impact ergonomics can create is vast as it involves huge variety of machines and long working hours on these equipment. Workers in this field have to endure painful working positions, continuous and repetitive movements of limbs, long standing hours etc. which can result in chronic injuries or illness. Ergonomic study and design of these equipments/machinery is very essential and can create a huge positive difference in productivity, health and satisfaction of the workers thus resulting in better agricultural productivity.

The application of ergonomics can help in increasing the efficiency and thereby productivity of the worker without jeopardizing their health and safety. The performance of any machine, especially manually operated ones could be considerably improved if ergonomic aspects are given due consideration (Gite, 1993). Systematic efforts to evaluate the energy cost of the harvesting practice of coconut climbing labourers by machine climbing are generally non-existent.

Human energy measurements are important because whenever the physical capacity of a person is exceeded, it is bound to cause considerable fatigue and reduction in the efficiency of the operation. Thus, investigations on ergonomic evaluation of farm equipment can provide a rational basis for recommendation of methods and improvement in equipment design for more output and safety.

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 and needs to be comparatively evaluated and modified. Considering these facts, the present research work "Evaluation of Physiological Cost and Subjective Assessment of Existing Coconut Climbing Devices" was taken up with the following specific objectives.

- To measure the pertinent anthropometric dimensions of human subjects with reference to the dimensions and positions of the functional components of coconut climbing devices.
- To measure the energy cost of the human subjects while using different models of coconut climbing devices.
- To assess the postural discomfort in terms of rating scales for the operation of the equipment.
- To incorporate modifications in the design features of the equipment for reduced drudgery and operational comfort of the human subject.

Review of literature

CHAPTER 2

REVIEW OF LITERATURE

A brief review of work done relevant to various aspects of the present investigation was reported. Important reviews of different coconut climbing devices, different steps in the ergonomic evaluation such as anthropometric dimensions, selection of subjects, calibration of the subjects, physiological responses and rating of perceived exertion of subjects were reviewed.

2.1 Palm climbing devices

Palm climbing devices are essential for harvesting coconut palms. Several commercial palm climbing devices which are available in markets are reviewed below.

Horace (1985) developed a palm climbing apparatus as shown in Fig 2.1. It comprised of a climbing platform with a platform yoke having a seat for supporting the user and a folding foot support having a foot support yoke and a cooperating foot platform for intermittent support of the user while the climbing platform was caused to ascend a palm engaged by the platform yoke and foot support yoke. Both the platform yoke and the foot support yoke features a Y-shaped segment and a removable blade for engaging the palm on opposite sides to support the platform yoke at a first selected elevation and the foot support yoke and companion foot platform at a second selected elevation beneath the platform yoke.

Williams (1989) developed a combined climbing and hang-on palm stand with optional climbing aid having a platform, a seat collapsible between a position overlying the platform and a position upstanding from the platform, and a climbing band for encircling the palm as shown in Fig 2.2. The platform, seat and band engage the palm at three discrete points to afford stability. A safety rope secured to the seat and was provided with a Chinese knot for tightening the rope against the palm. A climbing aid comprising generally of a rectangular frame with one 'end frame member' slidable towards and away from the opposite ‘end frame member’ to adjustably lock in a selected position depending upon the girth of the palm was provided.

Amacker (1992) developed a universal compact and versatile palm stand with a seating section (Fig 2.3) having at least one pair of longitudinal side members supporting a seat and means for gripping a palm connected at one end of the side members. A cross member was provided so as to reversibly extend the seating section which can also be completely removed from the seating section. A foot supporting section with a rectangular frame is divided into two frame sections. The two frame sections could be separated so that the frame was reassembled for climbing and used as a palm stand or disassembled to reduce the length of the foot supporting section for transportation and storage. The seating section can also be used as a hand climber.

Gardner (1992) developed a climbing palm stand as shown in Fig 2.4. The apparatus for climbing the palm comprise of two frames, each frame having a rigid base portion with flexible adjustable palm encircling band mounted thereon. A turnbuckle was connected to the end of each band for drawing together and separating the ends so as to change the effective length of the band. The rigid base portion of each frame had palm gripping edges which together with the bands and resiliently biased braces act to secure each frame to the palm. Adjustment of turn buckles changes the attitude of the base relative to the ground. One of the frame is positioned above the other on the palm and they are alternatively raised up the palm or lowered down the palm. The upper frame had a seat which hanged from the rigid base and was slidable, vertically adjustable and pivotable relative to the base. The lower frame had a platform upon which the foot of a user rests while standing or sitting on the seat. A pivotable brace member mounted on each base and resiliently urged against the palm aids in holding each frame against the palm during the climbing phase and the upper brace member functions as a back rest for the user.

Louk (1993) developed a hunter’s palm stand having two platforms as shown in Fig 2.5. Both platforms had a supporting metal frame, one covered with an open metal grid for standing, and other having a web fabric seat for comfortable seating. Each platform was supported by rigid folding side rails, which can be folded for easy storage. A flexible, encased steel cable extending from one side rail around the trunk of the palm is fastened to the other side rail, and adjusted in length by a snap ring clip. A blunt round edge toothed blade extending from the metal frame, in combination with the encased cable, holds the stand securely to the palm under load but without penetrating the bark or otherwise injuring the palm. The encased cable and folding support confirmed to the shape of the palm, and gave the user a secure feeling while climbing in the palm stand.

Reggin (1994) developed a portable palm stand assembly comprising of a horizontal platform easily mountable to a trunk of a palm as shown in Fig 2.6. A vertical mounting structure was connected to the rear side of the horizontal platform and extends vertically downward from the horizontal platform. A cantilevered support structure was connected between the front side of the horizontal platform and the base of vertical mounting structure, which allows the upper surface of the horizontal platform to be unobstructed. A plurality of spurs protruding rearward from the vertical mounting structure grips the surface of a palm without causing substantial damage to the palm. A link chain secured the stand to the palm without requiring cinching or tightening.

Stuart (1997) developed a palm stand shroud as shown in Fig 2.7. The shroud partially covers the hunter and encloses the palm stand during use. The shroud formed from a flexible camouflage fabric could be easily folded into a small package for carrying by the hunter. The shroud included loop straps fasteners along the top edge for releasable attaching the shroud to the palm stand. A draw cord along the bottom edges allowed the shroud to be closely gathered around the footrest section of the palm stand to prevent deer or other animals from being frightened by inadvertent movement of the hunter.

Louk *et al.* (1999) developed a convertible palm stand for rifle/bow use as shown in Fig 2.8. The palm stand consists of two platforms each having a supporting frame, one covered with an open grid member for standing, while the other had a seat for comfortable seating. The seating platform could be mounted to a palm in one of the two positions. One position would locate the front end thereof in a downward direction. This which opens the front end for use in bow hunting. The other or second position was inverted, with the front end located in an upward direction so that it would define a rest surface for rifle hunting. A flexible cable extending from one side of the outer end of the platform, through a side support around the palm to another pivotal side support was connected to the other side of the outer end, supporting each platform. The cable was adjustable in length to accommodate different diameter palms.

Morris (2002) developed a climbing palm stand (Fig 2.9) having a first platform and a second platform having a base frame, a first arm and a second arm, a support arm, first and second illumination assemblies, and a blade attached to an upper bracket of the base frame. The first and second arms were pivotally attached to the base frame and were releasably engageable with the support arm. The support arm had a curved portion at an opposed distal end of the first arm and second illumination assembly attached to a distal end of the second arm of each platform. The second platform included a foot support lifting bracket attached to its base frame. The foot support lifting bracket comprised of rigid non flexible structure.

Graham *et al*. (2003) developed an adjustable palm stand comprising of a seating section (Fig 2.10) and a standing section, each having inclined attachment bars adjacent the section sides, and seating and standing section cables, each having first and second ends with handles at each of the ends. Each attachment bar had outer and inner faces with a plurality of spaced, aligned attachment holes extending between the faces, and a plurality of spaced, aligned latch holes alternating with the attachment holes. Each of the handles had a pair of flanged projections insertable into adjacent attachment holes in an attachment bar, and a latch pin insertable into a latch hole between the adjacent holes. Each projection was moveable from an insertion position to a locked position within a hole when the cable was tensioned, and was prevented by the latch pin from moving back to the insertion position when the cable was relaxed.

Joseph (2006) developed a coconut-climbing device having two frames (left and right). Each frame had flexible adjustable encircling iron rope mounted around the palm and a palm gripping rubber pad. Each frame member had adjustable lock for changing rope length according to girth of the palm. An elastic strap helps the climber hold his feet inside a strap. The two main frames were fitted on the palm side by side enabling the operator to lift the frames conveniently using the sliding member.

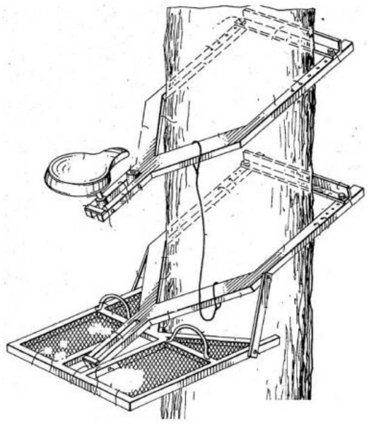


Fig 2.1 Palm climbing apparatus aid - Horace model

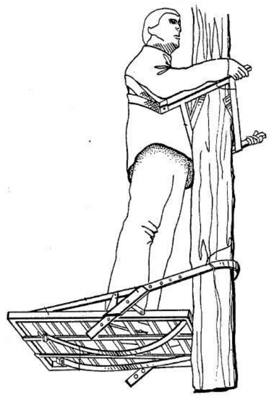


Fig 2.2 Hang on type palm climbing - Williams model

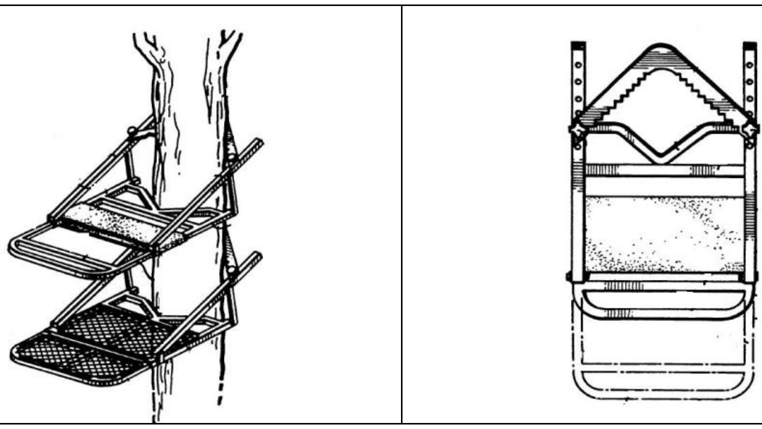
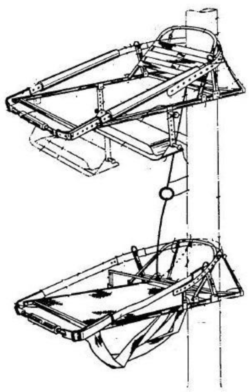


Fig 2.3 Universal palm stand - Amacker model



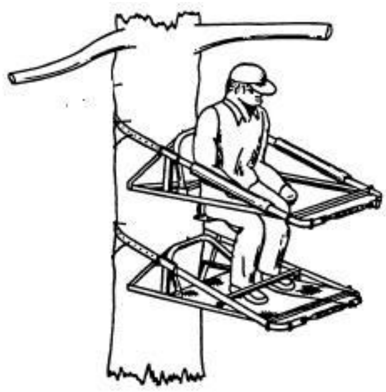
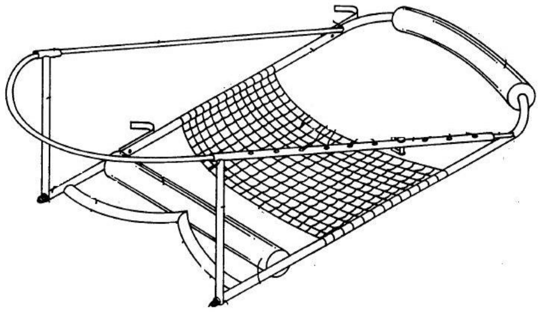


Fig 2.4 Climbing palm stand – Gardner model



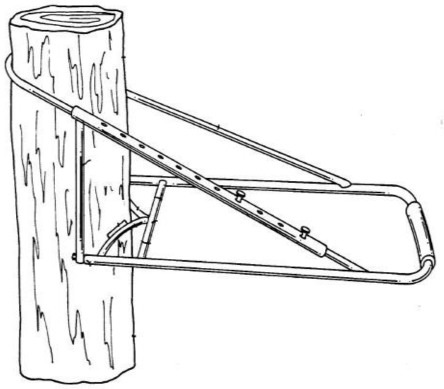
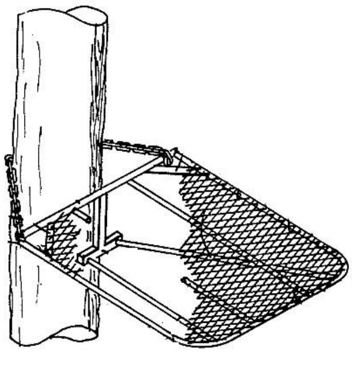


Fig 2.5 Hunter's palm stand – Louk model



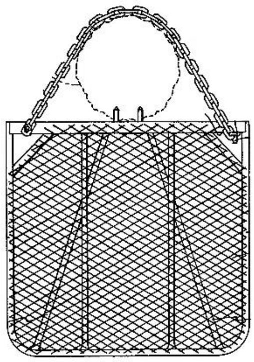
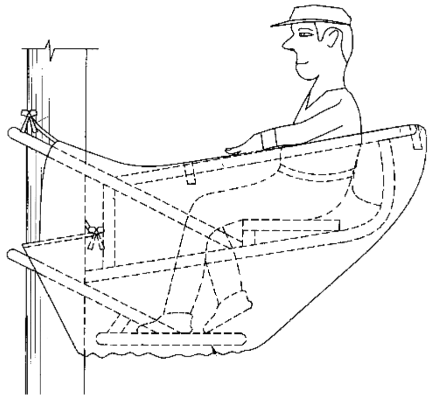


Fig 2.6 Portable palm stand assembly – Reggin model



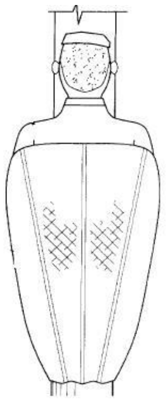


Fig 2.7 Palm stand shroud – Stuart model

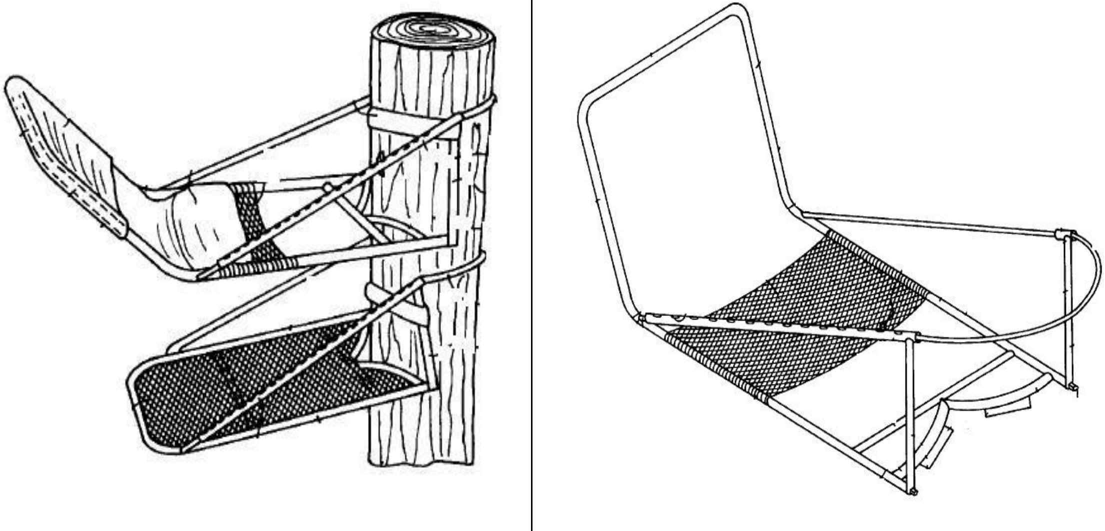


Fig 2.8 Convertible palm stand – Louk model

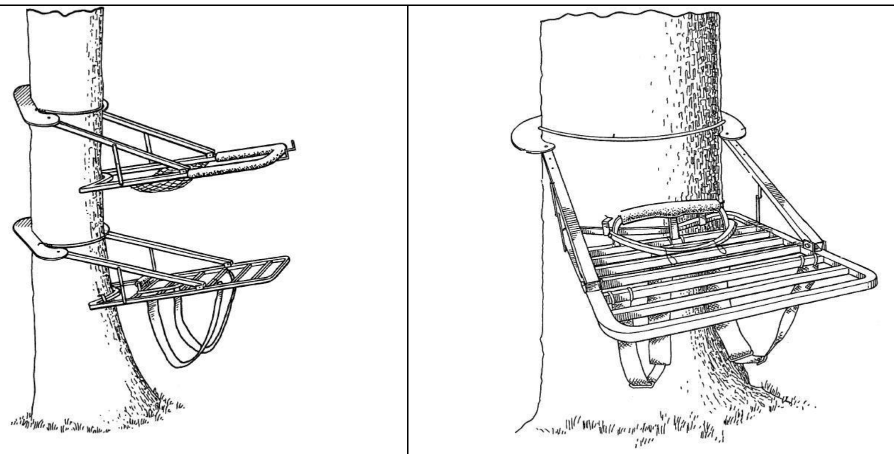


Fig 2.9 Climbing palm stand – Morris model

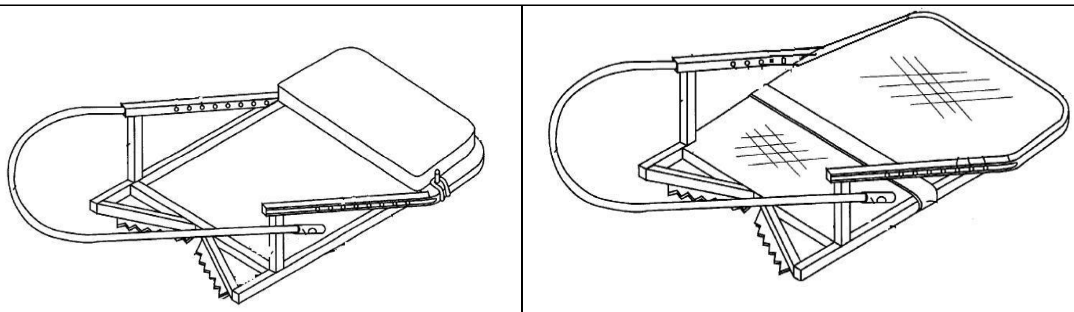


Fig 2.10 Adjustable palm stand – Graham model

Mohankumar *et al.* (2013) developed an ergo refined coconut climbing device. 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 was 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 of gravity of user to unsafe position and ensures stability. Back rest was also provided for user safety purpose.

2.2 Ergonomic evaluation

Brian *et al.* (1998) concluded on his study of ergonomic evaluation of hand-hoes for hillside weeding and soil preparation in Honduras that the application of ergonomics, in conjunction with other disciplines, to small-farmer mechanization problems can gave valuable insight into the differences between options and on their adoptability. Ergonomics is a vital element in the search for improved implement design for farmers working in marginal conditions.

Thyagarajan *et al.* (2012) stated that ergonomic evaluation of farm tools was necessary to improve the fit between the physical demands of the tools and the worker who performs the work.

Naieni *et al.*(2014) highlighted that ergonomists are capable of providing a safer work environment for the agricultural workers in both developing and developed countries. In addition, the results showed that it needs global cooperation of international organizations to enhance the occupational health intervention in agriculture.

2.2.1 Anthropometric dimensions

Anthropometry deals with measurement of physical features of human body. Comfort and performance of farm worker depend on their body dimensions. So, it is important to analyze the body dimension for using the machine comfortably.

Tiwari and Philip (2002) collected data from 137 female workers by conducting a preliminary anthropometric survey on women agricultural workers of Kerala and its implication on tool design were discussed.

Aware and Powar (2008) conducted a survey during 2004-2006 for anthropometric and strength data of agricultural workers from Konkan region. The survey points were distributed in four districts and data of 649 male and 377 female subjects were collected. The collected data were analyzed for its distribution and were modeled for prediction of some anthropometric parameters. This data could be used in design of various farm implements and equipment with respect to anthropometric suitability. It was also found that 13 anthropometric dimensions could be predicted utilizing 5 base parameters. Hence it would reduce the workload in anthropometric survey.

Agrawal *et al*. (2010) found the 5^{th}, 50^{th} and 95^{th} per centile values of grip diameter (inside) of male and female agricultural workers of Meghalaya as 3.7, 4.2 and 4.7 cm for male and 3.3, 3.6 and 4.1 cm for female workers, respectively. Also stated that the comfortable holding of the grip should be designed in such a way that a person with 5^{th} per centile body dimensions could properly grip the handle. The length of grip depended upon breadth of palm of the population and it should be decided based on 95^{th} per centile person operating the equipment so that he/she is able to hold the grip properly. The minimum handle grip length should be 9.9 cm for male and 9.5 cm for female operated tools.

Kanchan *et al.* (2010) analyzed the anthropometrical relationships within and between hand and foot dimensions. The study was conducted on 240 Rajputs (120 males and 120 females) from North India. The results showed a significant correlation between and within the dimensions of hands and feet.

Tshering and Rai (2011) observed high correlation between weight and height of selected males with the age ranging from 14 to 27. Anthropometric indices revealed that significant percentage of individuals were stunted, overweight or underweight. These low or high indices were the indicator of future health risks.

Shiru and shehu (2012) revealed that operators of cassava grating machines were in various sizes and ages. The anthropometric data collected were tested statistically and the statistical results could be used for modification of existing machines for better performance, designing of new machines and sitting facilities (stools and chairs) during operation.

Ismaila *et al.* (2013) measured various body dimensions (sitting elbow height, shoulder height, knee height, popliteal height, buttock-popliteal length, stature and body weight) of the students using standard anthropometer and 5^{th}, 50^{th}, and 95^{th} per centiles of the data obtained were computed using a SPSS 16.0 statistical package.

Sam (2013) conducted a study on anthropometry of Kerala female agricultural workers and design of hand tools of the region and collected anthropometric data from 120 female farm workers engaged in agriculture field activities in the age group of 19 to 65 years from Kerala, southern part of India. The mean, standard deviation, standard error of mean, coefficient of variation, relative accuracy and percentile values (5^{th}, 50^{th} and 95^{th}) of each measurement were tabulated. The means of the female measurements were compared with those obtained for the agricultural workers from other parts of the country and found that south indian female workers were shorter and heavier than female workers of western and north eastern part of India.

2.2.2 Selection of subjects

Selection of subjects have vital role in ergonomic evaluation. The selected subjects should have ability to perform work without any sudden fatigue or should be medically fit to do work. Three factors mainly considered for the selection are age, weight and medical fitness.

Astrand *et al.* (1965) stated that maximal oxygen uptake, heart rate, stroke volume, pulmonary ventilation and muscle strength decreased significantly with old age. The maximal aerobic power reached a peak at the age of 18-20 years followed by a gradual decline.

Reinberg *et al*. (1970) reported that the workers between 25 to 30 years old, both men and women reached peak muscle strength. Older workers between 50 and 60 years age could produce only about 75 to 80 per cent of muscular strength compared to their younger days.

Seidel *et al*. (1980) reported that the medical and bio-clinical investigations conducted to assess the medical fitness of selected subjects include Electro Cardio Graph (ECG), blood pressure and bio-clinical analysis

Grandjean (1982) observed that the maximum force a muscle or a group of muscle capable of depends upon age. The peak muscle strength for both man and women was reached between the ages of 25 and 35 years.

Grandjean (1988) inferred that the maximum percentage of work could be expected during 20 to 30 years, Based on the study of relation between the oxygen consumption and age of the workers.

Rodahl (1989) reported that maximum heart rate declines with age.

Mc Ardle *et al*. (1994) reported that the various measures of bodily function generally improve rapidly during childhood to reach a maximum between age 20 and 30 years and then a gradual decline in functional capacity with advancing years.

Gite and Singh (1997) reported that maximum strength could be expected from the age group of 25 to 35 years.

Nigg and Herzog (1999) reported that age group of 25 to 35 years had maximum muscle strength and cross sectional area of muscles.

Mc Ardle *et al.* (2001) concluded on his investigation of the strength of male and female workers that both usually attain the highest strength levels between 20-40 years of age. It was also reported that the arm strength deteriorates more slowly than leg strength for male and female workers.

2.2.3 Basal Metabolic Rate (BMR)

Basal metabolic rate is the minimum amount of energy that a body requires when lying in physiological and mental rest. BMR is measured under standardized conditions, conducted with the subject in a postprandial state.

Curteon (1947) reported that basal metabolic rate, heart beat rate and oxygen consumption rate were the pertinent parameters for assessing the human energy required for performing various types of operation.

Grandjean(1982) revealed that a resting person had steady expenditure of energy depending on size, weight and sex when a person was lying down with an empty stomach.

Narashingrao (1997) conducted investigation on the ergonomics of man machine system on sprayers and estimated the BMR of three subjects which were ranged from 1507 to 1744 kcal day^{-1} .

2.2.4 Calibration of subjects

Davies and Harris (1964) reported that in the beginning of an exercise the heart rate increased rapidly and reached a steady state by the end of sixth minute. At the start of the exercise, there was a rapid rose in pulse rate and the maximum pulse rate was achieved within 5 seconds.

Astrand and Rodhal (1977) found that there existed a linear relationship between the oxygen consumption and heart rate and hence those variables could be determined during the required task and an extrapolation could be made to determine the maximal heart rate and oxygen consumption. They stated that one of the most useful ways of assessing the workload was measuring the heart rate, since it could be measured easily.

Brockway (1978) stated that the heart beat rate predicts the energy expenditure. This study correlated the heart beat rate, oxygen consumption by indirect calorimetry and indicated the possibility of extrapolating the energy cost from the stabilized heart beat rate.

Roswe (1993) concluded that of the available physiological variables for assessing the workload, heart rate was the most useful. Heart rate and oxygen consumption had been used to assess the workload of human subjects.

Sanders and McCormick (1993) reported that heart rate was best used as a predictor of oxygen consumption when moderate to heavy work was performed. They also stated that heart rate continuously sampled over a work day or task, was useful as a general indicator of physiological stress without reference to oxygen consumption or energy expenditure. And they pointed that for different people the linear relationship between heart rate and oxygen consumption was different. So they suggested calibration of each person to determine the relationship between heart rate and oxygen consumption.

Kroemer *et al.* (2000) stated that measuring the heart rate was one of the most useful ways of assessing the workload as it could be done so easily.

Bridger (2008) stated that it was easy to measure heart rate of a subject but could not estimate energy expenditure. So, both variables had to be measured simultaneously in laboratory at different submaximal loads. That was the calibration of heart rate/VO_2 relationship for workers.

2.2.5 Physiological cost of work

Grandjean (1973) observed extensive use of heart rate as a measure to know the extent of stress particularly under static conditions. According to him, heart rate within certain limits increase in direct proportion to the energy expenditure.

Ganguly and Datta (1975) obtained a highly satisfactory linear relationship between the energy cost and peak heart rate in lower extremity amputees and in normal control subjects, during different activities. They also suggested an equation for predicting energy cost.

$$E = 0.068 \times PHR - 4.59 \qquad \text{------- (2.1)}$$

Where,

E = Energy cost in kcal min^{-1}.

PHR = Peak heart rate in beats min^{-1}.

Nag *et al.* (1980) found that average energy cost rate obtained over the working hours was 11.11 kg min^{-1} or about 28 percent of VO_2 max. It was suggested that the workers might be allowed to work up to the limit of 40 per cent VO_2 max, for longer duration, if an increase in productivity was desired. He also suggested that for long duration work the activity levels should not exceed 35 to 50 percent of VO_2 max, in excess of which a substantial amount of anaerobiosis occurred in the working muscles.

Intaranont and Srithongchai (1993) conducted a study on work strain of sugar-cane cutters to evaluate the profile of work strain of sugar-cane cutter and lifters using portable heart-rate monitoring machine. Further analysis was also conducted to investigate the effect of workers, task and environmental variables to the changes of heart rate.

Brian *et al.* (1998) have done ergonomic evaluation of hand-hoes for hillside weeding and soil preparation in Honduras. The physiological cost of hoeing increases with slope angle, but the hoe designs evaluated did not differ sufficiently to show differences in the effort required to use them. Reducing tillage to strip or zero till reduces the physiological demand and increases labour productivity.

Tiwari and Gite (1998) found that physiological cost of work was reduced with the use of improved maize sheller as compared to traditional method. The rate of perceived exertion for this traditional method was also reported to be moderately heavy, while, it was light with the use of maize sheller.

Sawkar (1999) showed that mean heart rate of picking of stalks and stubbles, sowing, transplanting, inter culturing, weeding and harvesting of wheat and jowar crop were 101.00±5.30, 110.60±4.20, 118.60±15.10, 131.00±7.00, 109.10±7.1, 126.00±7.00 and 123.00±5.0 beats min^{-1}, respectively. Similarly, the mean peak heart rate for the same activities were 119.40±3.30, 123.20±2.60, 130.00±13.70, 144.50±7.60, 122.80±5.2, 142.7±5.20, 136.20±4.10 beats min^{-1} respectively. This study revealed that the handling of tools, multiple postures adopted to perform the activity with lots of twists and turns, the forceful torque movements and the stature content involved in holding the posture to perform the activity.

Tiwari and Philip (2002) observed the energy cost of different agricultural work situations of female agricultural workers in West Bengal as 18.2 kJ min^{-1} in load carrying, 15.69 kJ min^{-1} in weeding, 14.88 kJ min^{-1} in transplanting, and 14.26 kJ min^{-1} in threshing and 13.46 kJmin^{-1} in harvesting.

Badiger *et al.* (2006) in his study on ergonomic evaluation of improved technologies for farm women found that in post harvest activities the average working heart rate in traditional and improved methods were 92.41 beatsmin^{-1} and 88.57 beats min^{-1}, respectively.

Kwatra *et al.*(2010) found that the HR work, ODR, ERR, and physiological cost of work reduced from 154.5 to 122.5 beats min^{-1}, 4.6 a score of 3.7, 17.64 to 12.80 kJ min^{-1} and 131 to 52.03 respectively when comparative study was undertaken between manual beating of paddy on drum and the use of paddy thresher (manually operated). The increase in heart rate per kg of grain threshed reduced significantly contrary to reduction of change in HR work by 20.71 per cent.

Kolhe *et al* (2011) evaluated the stability and ergonomic design features of tractor mounted hydraulic elevator for coconut harvesting. In this study, failures and safety of harvesting platform of Tractor Mounted Hydraulic Elevator (TMHE) powered by tractor PTO was tested by finite element method for the mechanical harvesting of coconut orchards using digital ergonomic heart rate meter.

Thyagarajan *et al.* (2012) was incorporated suitable ergonomic design refinement in the two row finger type rotary weeder for enhanced comfort of the operator without jeopardizing the efficiency of the tool. The two row finger type rotary weeder with ergo refinements enhanced the comfort of the subject with 15.16, 21.69, 21.68, 21.70, 36.37, 21.78 and 36.54 per cent reduction in heart rate, oxygen consumption, energy expenditure, AWL, LCP, Overall Discomfort Rating and Body Part Discomfort Score respectively.

Mohankumar *et al.* (2013) conducted a comparison study on newly developed ergo refined coconut climbing device and TNAU model. And found that the ergo refined coconut tree climbing device enhanced the comfort and safety of male subjects with 7.8, 12.2, 10.7 and 20.5 per cent reduction in heart rate, energy expenditure, overall discomfort rating and body part discomfort score, respectively and 2.6 and 4.1 per cent increase in overall safety and ease of operation rating respectively when compared to TNAU model. The ergo refined coconut tree climbing device resulted in 20.6 per cent savings in cost and 11.8 per cent savings in time of climbing and harvesting coconut when compared with TNAU model.

Singh *et al.* (2013) concluded that tubular maize sheller has about 43 per cent saving in cardiac cost of workers per unit of output in comparison to the hand shelling, in his study of ergonomic evaluation of farm women during maize shelling.

Sam (2014) found in her study of ergonomic evaluation of paddy harvester and thresher with farm women, that the maximum energy cost was 20.58 kJ min^{-1} for harvesting with sickle, whereas for harvesting with self-propelled harvester, this was 17.93 kJ min^{-1}. Harvesting after 11 am resulted in 18 per cent more energy cost than harvesting before 9 am. The energy cost was observed to be 15.53 kJ min^{-1} for threshing with mini thresher, whereas for manual threshing this value was 21.55 kJ min^{-1}. The oxygen consumption in terms of VO_2 max was above the acceptable work load for all selected operations.

2.2.6 Grade of work

Sen (1969) tentatively classified the manual jobs based on the physiological responses of young Indian male and female workers. The tentative classification of strains in different types of jobs was furnished in Table 2.1 and Table.2.2

Table 2.1 Classification of the manual jobs based on the physiological responses of male subjects

Grading	**Physiological response**		
	Heart rate (beats min^{-1})	**Oxygen uptake, (lit min^{-1})**	**Energy expenditure, (kcal min^{-1})**
Very light	<75	< 0.35	<1.75
Light	75-100	0.35 - 0.70	1.75-3.5
Moderately heavy	100-125	0.70 - 1.05	3.5-5.25
Heavy	125-150	1.05 - 1.40	5.25-7.00
Very heavy	150-175	1.40- 1.75	7.00-8.75
Extremely heavy	>175	> 1.75	>8.75

Table 2.2 Classification of the manual jobs based on the physiological responses of female subjects

Physiological cost	**Very light**	**Light**	**Moderately heavy**	**Heavy**	**Very heavy**	**Extremely heavy**
Heart rate, beats min^{-1}	< 90	91-105	106-120	121-135	136 -150	>150
Energy expenditure, kJ min^{-1}	< 5.0	5.10 - 7.50	7.60 - 10.00	10.1 - 12.50	12.60-15.00	>15.00

Nag *et al.* (1980) categorized the occupational work load in performing the agricultural activities. Work intensity of the agricultural operations were classified in terms of 'light', 'moderate', 'heavy' and 'extremely heavy' which corresponded up to 25 per cent, 25-50 per cent, 50-75 per cent and above 75 per cent of the maximal oxygen consumption respectively, obtained from rhythmic bicycle ergometry.

2.2.7 Acceptable work load

Astrand (1960) stated that it is necessary to compute the VO_2 max for each subject by conducting submaximal tests.

Saha *et al.* (1979) has given the acceptable workload (AWL) for Indian workers as the work consuming 35 per cent of VO_2 Max.

Gite (1993) reported that workload requires oxygen at a rate of about 35 per cent of VO_2 max, was considered as the acceptable workload for Indian workers and the values worked out to be 0.70 lit min^{-1} and 0.63 lit min^{-1} for male and female workers respectively. The corresponding heart rate values for this workload would be about 110 beats min^{-1} and 105 beats min^{-1}.

2.2.7.1 Maximum aerobic capacity (VO_2 max)

Astrand and Rodahl (1970) found that during continuous work lasting for atleast 5 to 6 min, oxygen consumption equalled oxygen demand and during the last 2 to 3 min of the activity, pulmonary ventilation, heart rate and other cardiovascular parameters were constant. They also reported the same heart rates at a given sub maximal workload in old and young. However, maximal oxygen uptake, heart rate, stroke volume, pulmonary ventilation and muscle strength decreased significantly with age.

NIOSH (1981) reported that there is increase in physiological parameters depending upon the workload, during any physical activity, and the maximum values, which could be attained in normal healthy individuals, will be up to VO_2 max. However at this extreme workload, a person can work only for a few seconds. The acceptable workloads for extended periods as 33 per cent of maximal aerobic capacity for an 8-hour shift and 28 per cent for 12 hour sift.

Gite and Singh (1997) stated that maximum aerobic capacity also called as maximum oxygen consumption capacity or VO_2 max was conceived as an international reference standard of cardio-respiratory fitness.

Muthamilselvan *et al.* (2006) observed that the heart rate of the subjects increased steadily from the beginning of the operation and stabilized in the range of 121.0 ± 4.56 beat min^{-1} after 6^{th} minute of operation. The average oxygen consumptions were 0.53 and 0.45 1it min^{-1} for machine and conventional picking respectively. Average energy cost for operation of the cotton picker was 11.16 kJ min^{-1} and the operation of the machine could be graded as 'moderately heavy'. The average per cent VO_2 max (29.71 per cent) was lesser than that of the acceptable work load (AWL) limits of 35 per cent.

Maximum aerobic capacities (VO_2 max) of Indian male and female agricultural workers as represented by various authors were presented in Table 2.6.

Table 2.3 Maximum aerobic capacity of agricultural workers

S.No.	Source	Maximum aerobic capacity (VO_2 max), lit min^{-1}
A. Male		
i	Nag (1981)	2.24
ii	Nag *et al*. (1988)	2.01
iii	Gite *et al.* (1996)	1.95
iv	Vidhu(2001)	1.69 - 1.92
v	Sam (2002)	1.98 - 2.48
vi	Sivakumar (2001)	1.69 - 1.92
vii	Balasankari (2003)	1.76 - 2.35
viii	Thiyagarajan (2013)	1.85 - 2.19
ix	Thambidurai (2007)	2.01 - 2.26
x	Mohankumar (2014)	1.98- 2.34
B. Female		
i	Nag (1981)	1.80
ii	Bimla *et al*.(2002)	1.76
iii	Singh *et al*. (2001)	1.60 - 1.87
iv	Sirisha (2004)	1.25 - 1.39
v	Thambidurai (2007)	1.56 -1.75

2.2.7.2 Limit of continuous performance (LCP)

Rodahl (1989) stated that the extend to which a person may increase his work rate depends in part on how much he can increase his heart rate from resting level to his maximum level, because the increase in heart rate plays a major role in increasing the cardiac output form rest to maximal work.

Tiwari and Gite (1998) calculated Δ values (Increase over resting values) for heart rate (work pulse), to have a meaningful comparison of physiological response. For this, the average values of the heart rate at rest level and at working condition were used. The calibration chart was used to predict the corresponding Δ values of oxygen consumption rate (ΔVO_2). The values of physiological responses i.e. heart rate (ΔHR) and oxygen consumption rate (ΔVO_2) of the ten subjects were averaged to get the mean value for all the selected implements. The calculated values of work pulse for each operation were compared with the acceptable work pulse values of 40 beats min^{-1}(Brundke, 1984).

2.2.8 Subject Rating of Perceived Exertion

Subjective self-reported estimates of effort expenditure might be quantified using rating of perceived exertion. As an investigating tool, Rating of Perceived Exertion (RPE) has proved to be useful adjuncts for studies in exercise physiology by researchers (Borg, 1962; Borg, 1970; Corlett and Bishop; 1976 and Legg and Mahanty, 1985).

Kroemer and Grandjean (2000) defined the fatigue symptom as a general sensation of weariness. They reported the subjective and objective symptoms *viz.*, subjective feeling of weariness, faintness and distaste for work, sluggish thinking, reduced alertness, poor and slow perception and unwillingness to work.

Borah *et al.* (2001) reported that out of 30 women, 70 per cent experienced severe pain in the shoulder joints and 68 per cent found low back pain due to long hours of bending for uprooting of seedlings.

2.2.8.1 Overall discomfort rating (ODR)

Borg (1962) developed a category scale for the rating of perceived excertion (RPE). The scale ranges from 6 to 20 with every second number anchored by verbal expressions.

In 1970s, Borg developed a 15-point graded category scale to increase the linearity between the ratings and the workload. Using this scale, Ratings of Perceived Exertion (RPE) values were shown to be approximately one-tenth of heart rate values for healthy, middle-aged men performing moderate to heavy exercise.

Corlett and Bishop (1976) developed a technique for the assessment of overall discomfort rating in which a 10 - point psychophysical rating scale (0 - no discomfort, 10 - extreme discomfort) was used.

Gite *et al.* (1993) while conducting ergonomic evaluation of manual weeders found that the postural discomfort varied from 3.0 to 5.1 on 8-point scale for 15 min of operation of each weeder.

Vidhu (2001) used the borg RPE 15 point scale and reported that the overall discomfort was maximum for conoweeder (16.13) followed by seeding with direct paddy seeder (14.70) harvesting with self-propelled paddy harvester (14.60) and transplanting with manually operated paddy transplanter (14.37) using 15 point overall discomfort rating scale.

Sirisha (2004) reported that the overall discomfort rate was maximum (7.55) for fertilizer broadcaster followed by conoweeder (7.15), seeding with four row paddy seeder (7.07), pulling stalks with cotton stalk puller (6.43), harvesting fruits with fruit harvester (6.37) and stripping with groundnut stripper (6.27) using 10 point overall discomfort rating scale.

Sam (2014) found that mean overall discomfort rating on a 10 point visual analogue discomfort scale (0- no discomfort, 10- extreme discomfort) was 6.6 and scaled as "moderate discomfort" for harvesting with self-propelled harvester whereas the rating was 8 and scaled as "more than moderate discomfort" for manual harvesting. Similarly, the rating was 6.3 and scaled as "moderate discomfort" for threshing with Mini Thresher while the rating was 8.5 and scaled as "more than moderate discomfort" for manual threshing.

2.2.8.2 Body Part Discomfort Score (BPDS)

Corlett and Bishop (1976) used body mapping for assessment of postural discomfort at work. In this method, the perceived discomfort was referred to a part of the body. The subject's body is divided into 27 regions and the subject was asked to indicate the regions which were most painful.

Lusted *et al.* (1994) developed a body area chart discomfort checklist. It was used to rate the discomfort under dynamic condition to identify body area experiencing discomfort. Two discomfort checklists are filled, one at the start of the test and the second after a long period in the seat. The ratings are then compared to estimate the level of discomfort.

Materials and Methods

CHAPTER 3

MATERIALS AND METHODS

In this chapter the selection of subjects and anthropometric measurements were detailed. The procedure followed for calibration of subjects and methodologies adopted for ergonomic evaluation of coconut climbing devices were narrated. The complete description of the constructional features of coconut climbing devices selected for the study was also given. The development of an ergonomically modified coconut climbing device was also discussed.

3.1 Selection of subjects

Subjects for the study were selected by conducting an anthropometric survey in three zones of Kerala. Those three zones are northern zone, central zone and southern zone. A sample of 60 subjects comprising 30 men and 30 women were selected from each of those zones. Pertinent anthropometric dimensions of human subjects with reference to the dimensions and positions of the functional components of coconut climbing devices were identified and 35 different body dimensions useful for the design or redesign of coconut climbing devices selected for the study were recorded by following standard anthropometric procedure. Ten subjects were selected (5 males and 5 females), those having anthropometric dimensions conforming to statistical requirements based on the anthropometric survey. The maximum strength or power could be expected from the age group of 25 to 35 years (Grandjean, 1982, Gite and Singh, 1997 and Umrikar *et al*, 2004). Hence subjects with age between 20 and 40 were selected for the study.

3.1.1 Anthropometry

Anthropometry is very important in ergonomic evaluation. It is a branch of human science which deals with measurement of human body with respect to bony marks. That may include linear dimensions, clearance, reach, posture, weight and volume. Some of the anthropometric dimensions used for the study are given in the Table 3.1.

Table 3.1 Anthropometric dimensions selected for the study

Sl No.	Dimensions	Sl No.	Dimensions
1	Weight	19	Age
2	Stature	20	Sitting popliteal height
3	Vertical reach	21	Knee height sitting
4	Vertical grip reach	22	Elbow rest height
5	Eye height	23	Buttock knee length
6	Acromial height	24	Buttock popliteal length
7	Elbow height	25	Hip breadth sitting
8	Olecranon height	26	Knee- knee breadth
9	Waist back length	27	Shoulder grip length
10	Arm reach from the wall	28	Elbow grip length
11	Waist breadth	29	Hand length
12	Hip breadth	30	Hand breadth at metacarpal III
13	Sittingheight	31	Hand breadth across thump
14	Vertical grip reach sitting	32	Palm length
15	Sitting eye height	33	Grip diameter (inside)
16	Sitting acromion height	34	Foot length
17	Hand grip strength (right)	35	Foot breadth
18	Hand grip strength (left)		

Following equipments were used for measuring anthropometric dimensions of the subjects

- Integrated Composite Anthropometer developed at IIT Kharagpur
- Digital hand grip dynamometer
- Grip size measuring device (cone)
- Medical balance

Plate 3.1 Integrated Composite Anthropometer

Plate 3.2 Digital hand grip dynamometer

Plate 3.3 Grip size measuring device (cone)

For measuring standing and sitting body dimensions Integrated Composite Anthropometer developed at IIT Kharagpur was used (Plate 3.1). Attention was taken to keep the Integrated Composite Anthropometer on plain surface without any undulations. The measurements were taken while subject was standing erect and up straight in posture. Hand grip strength was measured with Digital hand grip dynamometer (Plate 3.2) and Grip size measuring device (cone) was used for measuring internal grip diameter (Plate 3.3).

3.1.2 Medical fitness

The selected subjects should be fit to undergo trials, both mentally and physically. The subjects should not be pregnant, lactating or handicapped. An output of a job always depends on not only the level of skill but also their physical and mental strength. Seidel *et al*. (1980) had conducted medical and bio-clinical investigations to assess the medical fitness of selected subjects. The selected ten subjects were screened for normal health through medical and bio-clinical investigations which include Electro Cardio Graph (ECG), blood pressure and bio-clinical analysis.

3.2 Calibration

To evaluate the physiological workload using heart rate, the relationship between heart rate and oxygen consumption must be determined for each subject. Both variables have to be measured simultaneously in the laboratory at a number of sub maximal loads. This process is called calibration of subjects. Calibration is an important process to find out maximum oxygen consumption of a subject. Also calibration of the subject in the laboratory is essential as it helps in computing the energy cost in terms of oxygen consumption rate for the corresponding value of heart beat rate of the subject.

The subjects pedaled a standard Bi-cycle ergometer at predetermined speed and with varying breaking loads. Standard protocol was followed to record the data of oxygen consumption and the corresponding heart rate at different load conditions to arrive at the relationship between heart rate and oxygen consumption. The oxygen consumption was measured using Benedict- Roth Recording Spirometer and the heart beat rate using Polar pacer heart rate monitor.

3.2.1 Benedict- Roth Recording Spirometer

The BMR of the selected subjects was estimated by using Benedict- Roth Recording Spirometer (Plate 3.4). The apparatus consists of a 6 litre spirometer with a speed strip chart recorder. The spirometer bell was hung by means of a chain and counter weighed over a pulley. The counter weight carries the light Perspex ink writing pen. The main base was made of aluminium casting with leveling screws. It housed the kymograph gear box, 3 stop cocks one to serve as water outlet and the other two for oxygen outlet. The two outlets provided on the left side of the base are connected to the stop cock. One of the outlet housed a rubber outlet valve and the other had provision to take a thermometer. The two way stop cock (breathing valve) was carried by an adjustable arm and fitted with a rubber mouth piece through a corrugated rubber tubing. All air hoses are of 25 mm inside diameter. The speed of the spirometer was adjusted to 20 min/rev with the help of the speed selector.

Plate 3.4 Benedict- Roth Recording Spirometer with cycle ergometer

3.2.2 Polar pacer heart rate monitor

It is a compact portable instrument to monitor the heart beat rate. This can be used in the field directly where the telemetry system cannot be used. The heart rate of the selected subjects was measured using this Polar heart rate monitor (Plate 3.5).

Plate 3.5 Polar pacer heart rate monitor

This heart rate monitor has three basic components.

i. Chest belt transmitter

ii. Elastic strap

iii. Receiver unit

3.2.2.1 Chest belt transmitter

It has two electrodes with a grooved rectangular area on the underside of the belt transmitter, which picks up heart beat rate from the body of the subject and converts into electromagnetic signals. For better sensing the electrodes are wetted with water.

3.2.2.2 Elastic strap

This is to secure the belt transmitter as high under the pectorial muscles (breasts) as comfortable. The belt transmitter should fit snugly and comfortably and allow normal breathing.

3.2.2.3 Receiver

This is a unit which receives the signals from the transmitter and displays it on screen with the help of battery fixed in it. This receiver unit must be placed within one meter range and it can be fitted in watch strap. This receiver has two buttons below the screen to operate the heart beat rate monitor. This has provision to set up high target zone and low target zone limits. When the subject reaches the limits of heart beat it will indicate through alarm, or visual alarm, so that we can stop exerting the subject beyond this level. Similarly the low heart beat rate target zone will be helpful in certain critical condition. This receiver is also water resistant to 20m water column.

3.2.3 Basal Metabolic Rate

Before calibration basal metabolic rate has to be measured. Energy cost of a human in his resting state can be calculated by determining basal metabolic rate of that human. Basal metabolic rate was measured by Benedict- Roth Recording Spirometer. This was measured when the subject is in post absorptive state. The subject was allowed to take rest for half an hour in a semi reclining position before the commencement of the test. Benedict- Roth Recording Spirometer bell was filled with oxygen from the storage oxygen cylinder. The mouth piece was connected to the apparatus safely and properly, and then fitted to the subject. Clip the nose of the subject with the help of nose clip. The subject was initially allowed to inhale atmospheric air for some time. After normalization of breathing rate, turn the saddle valve on to oxygen present in the spirometer bell. The subject inhaled oxygen through the inspirating valve which was connected to the spirometer filled with oxygen and released carbon dioxide through the expiratory valve coupled to carbon dioxide absorber. The kymograph recorded the oxygen consumption on the strip chart. A satisfactory uninterrupted section of exactly six minutes were chosen from the chart for computation of BMR**.** Oxygen consumed per 6 minute was corrected under standard temperature and pressure for calculation of BMR. The same procedure was repeated for all selected subjects.

3.2.4 Calibration process

For calibration of the selected subjects, Bi-cycle ergometer and Benedict-Roth Recording Spirometer were used simultaneously as shown in Plate 3.6. Before starting the experiment, all the subjects were properly trained for one month in using the instruments separately and in combination. The instrument operation was demonstrated to the subjects to familiarize them with the instruments so that they can use the instruments without any tension and fear. The electrodes contained in the chest belt transmitter of polar pacer heart rate monitor were wetted with water and fastened on the chest of the subject. The subject was allowed to take rest for half an hour in a semi reclining position before the

Plate 3.6 Calibration process of subjects

commencement of the test. The Benedict-Roth spirometer was set up for calibration. The spirometer bell was filled with oxygen and the subject was fitted with the mouthpiece and nose clip. The subject inhaled the atmospheric air through mouthpiece at the initial stage. Heart rate was monitored on the display unit. After normalization of breathing rate, turn the saddle valve on to oxygen present in the spirometer bell. The subject inhaled oxygen through the inspiriting valve which was connected to the spirometer filled with oxygen and released carbon dioxide through the expiratory valve coupled to carbon dioxide absorber. Then the workload of the subjects was increased gradually by increasing the resistance to the pedals using Tension knob until the subject was exhausted. The kymograph started recording the oxygen consumption pattern of the subject on the chart continuously. Simultaneously the heart rate was recorded in the heart rate monitor fitted with the subject. The same procedure was repeated for all the subjects. By using the data on heart rate and oxygen consumption rate, calibration chart was prepared with heart rate as the ordinate and the oxygen consumption as the abscissa for the selected ten subjects.

3.3 Selection of coconut climbing devices

3.3.1 Sit and climb type (TNAU model)

A coconut climbing device was developed under All India Coordinated Research project on Farm Coconut climbing devices and Machinery in TNAU during 2006. The device comprises of an upper frame and a lower frame which are independently movable and positionable along the coconut trunk as shown in plate 3.7. The upper frame member is a tubular frame with rectangular cross section consisting of a rigid base section and an adjustable palm 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 palm 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.

Plate 3.7 Sit and climb type (TNAU model)

The palm gripping section has gripping aids to engage it on three points on the circumference of the palm. 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 palm trunk, thereby permitting the upper frame member to be fixed to the palm. 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 palm.

The lower frame member is also a tubular frame work consisting of a rigid base section and a palm gripping section similar to upper frame member except that the rigid base section is located adjacent to the palm trunk to support the weight of the user when the upper frame is repositioned on coconut palm. 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 canvas belt to prevent them from slipping down the palm trunk. Handles provided on the side rails of the upper frame enable the user to lift the unit while ascending or descending the palm. After reaching the coconut palm top, the unit can be fitted to one of the fronds with the help of a hook so that the user can harvest 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 is horizontal or parallel to the ground. To ascend the coconut palm, the user places his feet on the lower frame member, and 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 uses his hand to raise the upper frame to waist high position. The user then sits and again raises the lower frame with his feet and legs.

3.3.2 Standing type (Chemberi model)

This coconut climbing device was developed by Mr. M.J.Joseph, a farmer from Chemberi village of Kannur district 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 of flexible adjustable encircling iron rope of 8 mm diameter and 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 of bolts and wing nuts to fasten the ropes. The main frames having the foot rest comprise of 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 side by side enabling the operator to lift the frames conveniently using the sliding member.

Plate 3.8 Standing type (Chemberi model)

Before climbing, the climber fixes the climbing device, both left and right units, to the palm with the help of the wire rope provided. The climber holds the handles of both the 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 which leads to jamming of the device.

3.3.3 KAU coconut palm climbing device (developed at KCAET)

Plate 3.9 KAU coconut palm climber (developed at KCAET)

This model is developed by KAU 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 have 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. A specially designed footwear is also introduced to the lower frame that is easier to use and it is the one of the major advantage over other models. The equipment weighs 9.45 Kg.

3.3.4 Kerasuraksha coconut climbing device (developed at ARS Mannuthy)

This model was developed in ARS Mannuthy. This simple device consisted of an upper frame, the seating unit, lower frame and the pedal unit, which are independently movable and positionable along the coconut palm trunk. The upper frame member, is a tubular frame work made of stainless steel and consisting of a rigid base section and an adjustable palm gripping section. The rigid base section carries a seating arrangement for accommodating the user, side rail for hand support on one side, a V shaped portion with rubber blocks on both V's that grips to the coconut trunk from front side and a hand rail running above the V section. The seating structure is chair like and is linked to the V shaped portion mentioned earlier. Hand support on one side provides safety and easier entry and exit for the climber from the set up.

Plate 3.10 Kerasuraksha coconut climbing device

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 the slots after matching the slots in the sitting and gripping sections. These pins enable easy harnessing and pin slot can be chosen as per the coconut trunk diameter. Lynch pin harnessing method provide easy harnessing and dismantling within 26-10 seconds respectively. 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 member is also a tubular frame work consisting of a rigid base section and a palm gripping section similar to upper frame member except that the rigid base section is located adjacent to the palm trunk to support the weight of the user when the upper frame is repositioned on coconut palm. The rigid base section has a pedal like section and a V shaped portion with rubber blocks on both V's that grips to the coconut trunk from front side, 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 frame members are connected with canvass belt to prevent them from slipping down the palm trunk.

The Lynch pin harnessing mechanism in this equipment makes harnessing and dismantling very easy with an average user taking 26 seconds and 10 seconds respectively for harnessing and dismantling. Total weight of the machine is 8.4 kg and it can lift a maximum of about 400 kg.

3.3.5 CPCRI model coconut climbing device

This model is developed at CPCRI Kasaragod. This model is almost same as that of Chemberi model. They have done a small modification in Standing type (Chemberi model) by incorporating a safety device for the safety and comfort of the climbers to climb the coconut tree. For that, the main frame of the climbing device is provided with two metal loops at the bottom of the handle. A steel rope having 6mm diameter is provided with hooks at both ends. The wire rope can be taken through the loops provided in the climbing device and take around the palm to make it a noose and the free end is connected to a body harness which the climber has worn. The wire rope moves up and down along with the climbing machine during operation. In case of any eventuality, failure of the machine or accidental falling of the climber from the machine, the wire rope noose gets tightened to the coconut trunk and prevents the climber from further falling. The climber after falling can lock the machine and step back to it and continue climbing

Plate 3.11 CPCRI model coconut climbing device

3.4 Ergonomic evaluation of selected coconut climbing devices

Ergonomic evaluations of the selected coconut climbing devices were conducted for assessing their performance. The study was conducted at the farm of Farming Systems Reasearch Station, Kottarakkara and a coconut tree with 8 m height and 30.5cm diameter. The subjects were given information about the experimental requirements so as to enlist their full cooperation. A thorough training was given to the subjects to get familiarized with the coconut climbing device, who have already experience in coconut climbing for a week until they get ease on that. The work was started after attaining a complete experience on each device. They were asked to report at the work site at 7.30 AM and rest for 30 minutes before starting the trial. The electrodes contained in the chest belt transmitter of polar pacer heart rate monitor were wetted with water and fastened on the chest of the subject. Each trial started with taking five minutes data for physiological responses of the subjects while resting on a stool under shade. Heart rate during the climbing was measured by heart rate monitor. Each trial was replicated three times for each subject. The same procedure was repeated for testing five selected coconut climbing devices for ten subjects.

3.4.1 Energy cost of operation

From the values of heart rate (HR) observed during the trials, the corresponding values of oxygen consumption rate (VO_2) of the subjects for all the selected coconut climbing devices were predicted from the calibration chart of the subjects. The energy cost of operation of the selected coconut climbing devices were computed by multiplying the oxygen consumed by the subject during the trial period with the calorific value of oxygen as 20.88 kJ lit^{-1} (Nag *et al*. 1980) for all the subjects.

The values of heart rate, oxygen consumption and the energy cost for all the subjects were averaged to get the mean values for all the selected coconut climbing devices. The energy cost of the subjects for the selected coconut climbing devices thus obtained was graded as per the tentative classification of strains in different types of jobs according to the young Indian male workers given in ICMR report (Sen, 1969)

Statistical analysis of heart rate and energy cost for both male and female subjects were done by using SPSS 16.0 statistical package.

3.4.2 Acceptable work load

The work load should be expressed as a percentage of the individual's maximal aerobic power i.e. how much of the individual's maximal aerobic power has to be taxed in order to accomplish the work in question. Ideally, therefore, the individual maximal oxygen (O_2) uptake should be determined, and the workload should be similarly assessed individually. Saha (1979) has given the acceptable workload (AWL) for Indian workers as the work consuming 35 per cent of VO_2 Max.

3.4.2.1 Maximum aerobic capacity

The maximum oxygen consumption is the highest oxygen consumption attained by the subject where a further increase in workload will not result in an increase in oxygen uptake. The maximum aerobic capacity also called as maximum oxygen consumption capacity or VO_2 max is conceived as an international reference standard of cardio-respiratory fitness (Gite and Singh, 1997). Maximum oxygen consumption (VO_2 max) was estimated using the data on the heart rate-oxygen consumption relationship. Each subject's maximum heart rate was estimated by the following relationship (Bridger, 1995).

$$\text{Maximum heart rate (beatsmin}^{-1}\text{)} = 200 - 0.65 \times \text{Age in years}$$

The intersection of the computed maximum heart rate of the subjects with the plotted calibration chart line and the line of fit to the oxygen consumption defines the maximum aerobic capacity (VO_2 max) of the individual. To ascertain whether the operation of all the selected coconut climbing devices are within the acceptable workload (AWL), the VO_2 max for each treatment was computed and recorded.

3.4.3 Limit of continuous performance

The extent to which a person may increase his work rate depends in part on how much he can increase his heart rate from resting level to his maximum level, because the increase in heart rate plays a major role in increasing the cardiac output form rest to maximal work (Rodahl, 1989). For this, the average values of the heart rate at rest level and at working condition were used.

The values of resting heart rate and heart rate during climbing were taken for each selected coconut climbing devices. The values of physiological responses i.e. heart rate (ΔHR) of the five subjects were averaged to get the mean value for all the selected coconut climbing devices. The calculated values of work pulse for each operation were compared with the acceptable work pulse values of 40 beats min^{-1}(Brundke, 1984).

3.5 Subjective rating scales

3.5.1 Overall Discomfort Rating (ODR)

For the assessment of overall discomfort rating a 10 - point psychophysical rating scale (0 - no discomfort, 10 - extreme discomfort) was used. A scale of 70 cm length was fabricated having 0 to 10 digits marked on it equidistantly. A moveable pointer was provided to indicate the rating. At the end of each trial, subjects were asked to indicate their overall discomfort rating on the scale. The overall discomfort ratings given by each of the ten subjects were added and averaged to get the mean rating.

3.5.2 Overall Safety Rating (OSR)

For the assessment of safety rating, a 10 - point psychophysical rating scale (0 – completely secure and no fear, 10 – totally insecure and extreme fear) was used. A scale of 70 cm length was fabricated having 0 to 10 digits marked on it equidistantly. A moveable pointer was provided to indicate the rating. At the end of each trial, subjects were asked to indicate their safety rating on the scale. The overall safety ratings given by each of the ten subjects were added and averaged to get the mean rating.

3.5.3 Overall Ease of Operation Rating (OER)

For the assessment of ease of operation, a 10 - point psychophysical rating scale (0 – very easy, 10 – extremely difficult) was used. A scale of 70 cm length was fabricated having 0 to 10 digits marked on it equidistantly. A moveable pointer was provided to indicate the rating. At the end of each trial, subjects were asked to indicate their ease of operation rating on the scale. The overall ease of operation ratings given by each of the ten subjects were added and averaged to get the mean rating. The scale for ODR, OSR and OER are given in Table 3.1.

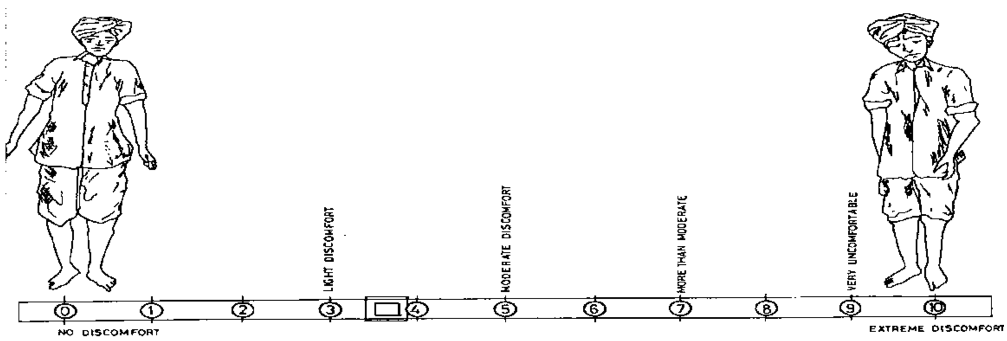


Fig. 3.1 Visual analogue discomfort scale for assessment of discomfort

Table 3.2 Scale for ODR, OSR and 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

3.5.4 Body Part Discomfort Score (BPDS)

A body mapping similar to that of Fig. 3.2 was made with thermocoal to have meaningful rating of the perceived exertion of the subject (Corlett and Bishop (1976)). The subject was asked to mention all body parts with discomfort, starting with the worst, the second worst and so on until all parts have been mentioned. The maximum number of intensity levels of pain experienced for the operation of the unit will have to be categorized. The rating will be assigned to these categories in an arithmetic order as explained below. *viz*., If the maximum number of intensity levels of pain experienced for the operation was 6 categories, first category (body parts experiencing maximum pain) rating was maximum as 6 and for second category (body parts experiencing next maximum pain) rating was allotted as 5 and so on, for the sixth category (body parts experiencing least pain) rating was allotted as 1. The number of intensity levels of pain experienced by different subjects might vary. For example, if one subject has experienced 4 categories, first category (body parts experiencing maximum pain) rating was allotted as 6 and for second category (body parts experiencing next maximum pain) rating was allotted as 4.5 and so on for the fourth category (body parts experiencing least pain) rating was allotted as 1.5. The body part discomfort score of each subject will be the rating multiplied by the number of body parts corresponding to each category. The total body part score for a subject will be the sum of all individual scores of the body parts assigned by the subject. The body discomfort score of all the subjects is to be added and averaged to get mean score. The same procedure was repeated for all the coconut climbing devices with all the selected subjects.

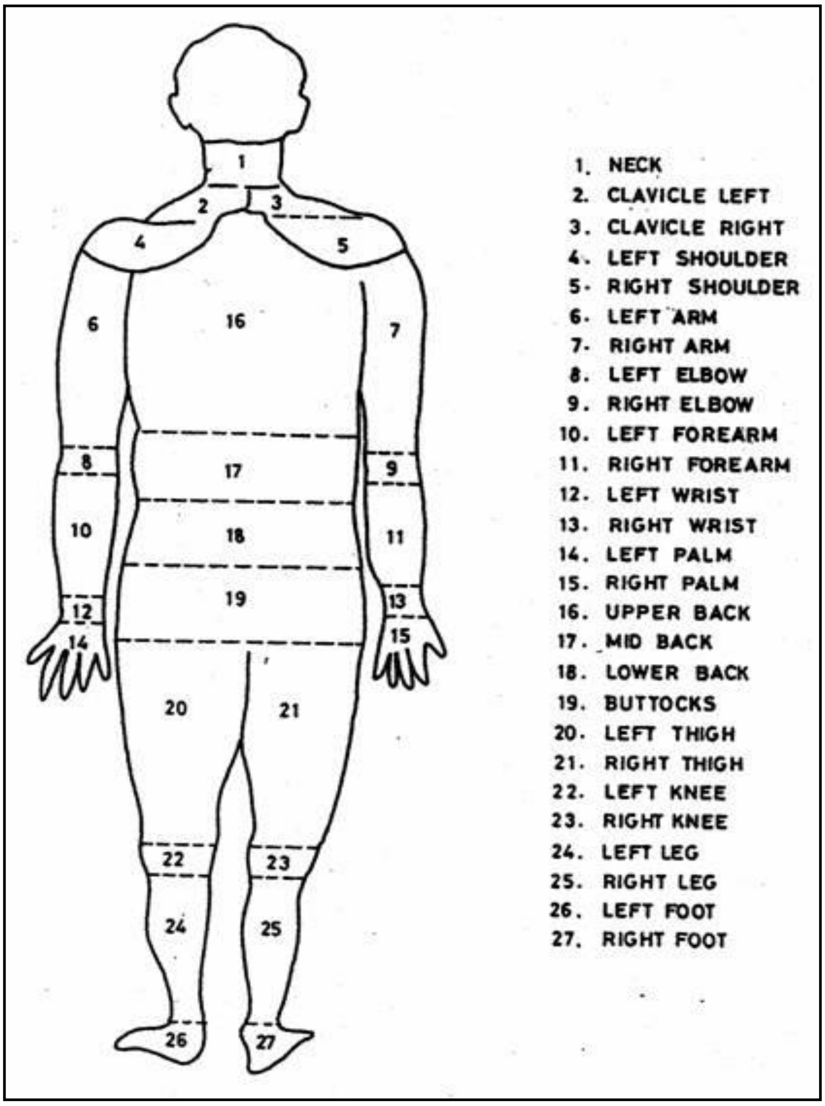
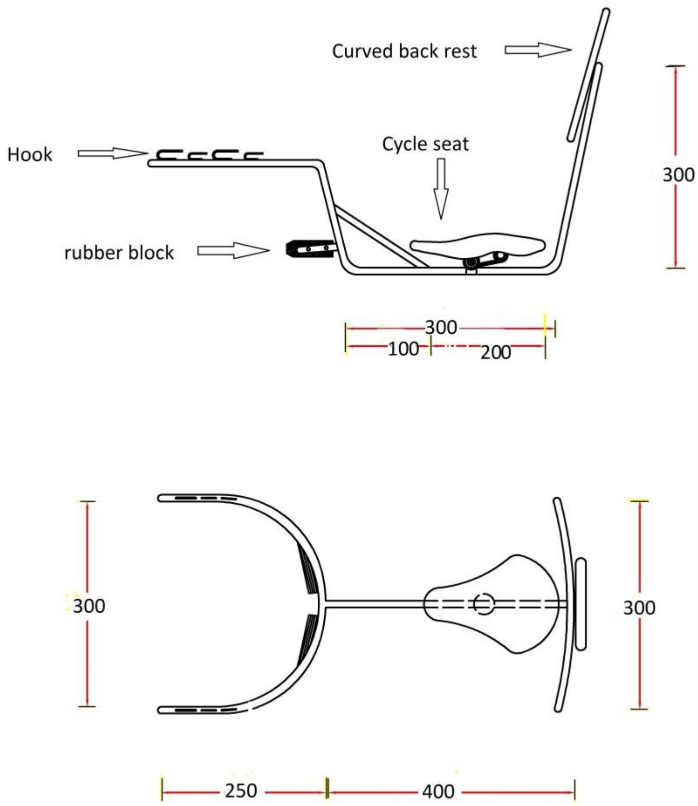


Fig. 3.2 Regions for evaluating BPDS

3.6 Modifications of coconut climbing device

Modification of coconut climbing device by considering the ergonomic factors may reduce the fatigue of work by increasing comfort and safety. Based on ergonomic evaluation and subjects' feedback, ODR, OSR, OER and BPDS a suitable ergonomically designed coconut climbing device was modified.

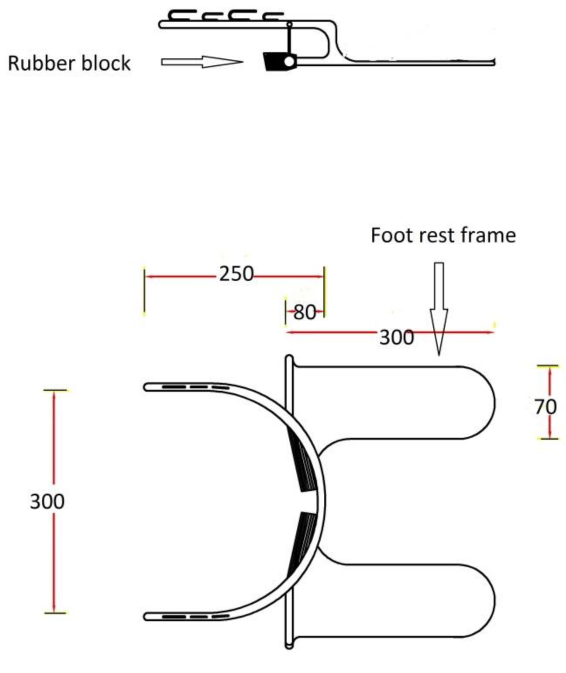
Based on ergonomic study conducted on the five equipments, the KAU palm climber (developed at KCAET) and Kerasuraksha (developed at ARS Mannuthy) were identified as more suitable for the climbers than the other three equipments. Hence these two models were taken for further modification to try and design a better ergonomically designed model. Hence the seating portion of Kerasuraksha coconut climbing device and the lower frame portion of KAU model were chosen for further modifications to arrive at better equipment.



All dimensions are in mm

Fig. 3.3 Design of upper frame of new mode

Plate 3.12 Upper frame of new model



All dimensions are in mm

Fig. 3.4 Design of lower frame of new model

Plate 3.13 Lower frame of new model

Mild Steel was chosen as the material for construction considering various factors like load bearing capacity and cost of final product. This device consists of an upper frame and lower frame. The upper frame has a seating part and palm gripping part. The seating unit has a cycle seat and curved back rest for comfortable seating. The seating position has been moved closer to the tree to reduce the rotating moment and hence load acting on the metal. This has also made it easier for the climber to access the tree while plucking and cutting. Near the tree side of the upper frame is the palm gripping part which has two portions. The main tree holding part and the bottom gripping portion. The main tree holding part is semi-circular in shape and covers the tree from one side. This is positioned above the seating portion. The portion has metal hooks arranged in sequence on both sides. The connection to the tree is made firm using thick metal wires that are connected to hooks on both sides of the equipment surrounding the tree. This arrangement gives excellent grip on the tree. As per the trunk size of the tree, the wires can be attached to appropriate hooks to adjust the radius. Two handles are also provided on this part which the climber can use for moving the equipment while climbing up and down. The bottom gripping portion of the upper frame is V shaped with two rubber blocks on either side for gripping. This is placed in line to the seating position and pushes against the tree when the climber sits, giving added gripping on the trunk while the climber sits or does his work.

The lower frame consists of a palm gripping portion and two pedal seats. The palm gripping portion has two parts, upper part and lower part. The upper part is exactly same in construction as that of the main tree holding portion of the upper frame. Just below this part is the lower part that has two rubber blocks on either side for gripping the tree trunk. The two pedals of the lower frame are attached to the backside of these rubber blocks. When the climber applies pressure on the pedals, these rubber blocks and the metal wires on the upper part of the lower frame together gives excellent gripping.

The climber first wraps the upper frame at his waist height on to the coconut tree. The curved part of the frame touched the tree and the frame is wrapped to the tree using two metal loops connected to the hooks on the upper frame. Two loops are used for added strength. The lower frame is wrapped to the coconut tree at the bottom. This is wrapped in the same way as the upper frame. The climber now sits on the seat on the upper frame. His weight will increase the grip on the tree as the rubber bead on the upper frame and the metal loop now holds well on the tree. The climber has to now insert his legs on the footwear on the lower frame. When he pushes his leg down the lower frame also gets a good grip similar to the upper frame. This is the ideal seating position for the climber.

Now he raises his legs closer to his body, raising the lower frame also along with it. Once he bends his legs to the maximum, he pushes his legs down quickly to grip the lower frame closer to the upper frame. Now using this grip he stands on the lower frame raising the upper frame along with him, holding the upper frame on the two hand grips provided. Once he raises the upper frame to his new seating position, he sits on the upper frame to establish a grip on the coconut tree. Again he raises his legs to being the lower frame closer to upper frame. This process continues which helps the climber climb up the tree. Similarly, to climb down the tree, the opposite order is to be followed. The upper frame is to be brought closer to the lower frame and gripped. Now the lower frame is to be taken further down and gripped. This helps the climber climb down.

Ergonomic evaluation of new model also conducted as per the procedure explained in section 3.4 and also the results were compared with other five models.

Results and Discussion

CHAPTER 4

RESULTS AND DISCUSSION

This chapter explained with the analysis of anthropometric data, calibration process and computed values of oxygen consumption and energy cost during the operation of different coconut climbing devices. The overall discomfort rating, overall safety rating, overall ease of operation rating, body parts discomfort scores were measured and discussed. Comparison of the oxygen consumption, energy cost, overall discomfort rating, overall safety rating, overall ease of operation rating and body parts discomfort scores of new model with selected five models was also done.

4.1 Selection of subjects

Subjects were selected from three zones of Kerala by analyzing a set of anthropometric data and selected subjects were bio clinically tested for checking whether subjects were medically fit or not .

4.1.1 Analysis of anthropometric data

Anthropometric data of 90 male and 90 female subjects were collected from three zones all over the state of Kerala, and were statistically analyzed. Statistical tools such as mean, standard deviation, percentiles and range were used for the analysis. Percentiles are important in the study of ergonomics, in that 5^{th} per centile indicates maximum product dimensions when reaches are involved and 95^{th} per centile indicates minimum product dimensions involving clearances. The statistically analyzed data of both men and women were given in Table 4.1 and 4.2 respectively.

Table 4.1 Analyzed anthropometric data of male subjects

Male							
Dimensions	Mean	Standard deviation	Per centile			Range	
			5th	50th	95^{th}	Min	Max
Weight, Kg	62.2	9.5	48.6	60.0	80.5	40.0	89.0
Stature	163.5	7.1	151.3	163.0	175.5	140.0	177.0
Vertical reach	209.9	9.9	195.0	209.5	226.0	175.0	232.0
Vertical grip reach	199.2	9.4	183.8	198.5	214.5	165.5	221.0
Eye height	152.7	6.9	140.6	153.0	164.5	128.0	166.0
Acromial height	137.7	6.6	127.8	137.3	148.5	115.5	152.5
Elbow height	104.2	5.8	95.1	104.0	114.2	87.5	118.0
Olecranon height	102.1	8.3	92.6	101.0	112.9	85.0	161.0
Waist back length	42.0	3.9	34.3	42.0	49.3	33.0	50.0
Arm reach from the wall	85.6	4.5	78.0	86.0	92.5	75.0	96.0
Waist breadth	30.1	3.1	25.1	30.0	35.2	22.0	41.5
Hip breadth	31.9	2.9	26.7	32.0	36.1	25.0	42.0
Sitting height	84.1	4.2	76.6	84.5	90.2	72.0	93.0
Vertical grip reach sitting	120.5	6.3	108.6	121.0	131.0	101.0	133.0
Sitting eye height	75.0	5.3	65.8	75.0	80.7	63.5	109.0
Sitting acromion height	58.5	4.1	51.0	59.0	64.5	45.0	70.0
Sitting popliteal height	45.5	3.4	40.0	45.3	51.0	38.0	56.0
Knee height sitting	54.9	3.6	48.6	55.0	60.0	46.0	63.5
Thigh clearance height sitting	12.7	2.0	10.0	12.3	16.5	9.0	18.0
Elbow rest height	23.1	4.3	17.0	23.0	28.5	15.0	48.0
Buttock knee length	55.6	4.4	47.6	55.8	62.7	46.0	69.7
Buttock popliteal length	45.9	3.5	40.2	46.0	50.7	37.0	61.0
Knee- knee breadth	14.7	2.8	10.8	14.4	19.6	10.0	27.0
Shoulder grip length	60.0	4.5	52.1	60.0	67.7	47.0	70.0
Elbow grip length	34.9	4.8	27.2	34.5	40.7	23.0	59.2
Hand length	17.6	1.2	15.6	17.7	19.3	14.4	21.5

Hand breadth at metacarpal III	8.1	1.0	6.9	8.0	10.1	6.4	11.0
Palm length	9.7	0.7	8.5	9.8	10.9	7.9	11.5
Grip diameter (inside)	13.8	1.6	11.0	14.0	16.5	10.0	18.0
Foot length	24.1	1.6	21.3	24.0	26.3	19.7	29.6
Foot breadth	9.0	1.0	7.0	9.1	10.5	5.9	11.0
Hand grip strength(right)	34.9	7.7	23.9	34.5	46.4	15.6	67.5
Hand grip strength (left)	34.8	7.1	24.4	34.9	48.0	14.6	57.2

(Unit: cm unless otherwise specified)

Table 4.2 Analyzed anthropometric data of female subjects

Female							
Dimension	Mean	Standard deviation	Per centile			Range	
			5th	50th	95th	Min	Max
Age in years	42.4	7.5	30.1	43.5	55.0	24.0	57.0
Weight, Kg	54.5	9.1	42.0	53.0	75.0	39.0	80.0
Stature	149.6	5.9	141.6	149.3	160.0	136.0	167.0
Vertical reach	188.9	7.8	177.6	189.0	202.5	170.0	211.0
Vertical grip reach	179.7	7.2	168.1	180.0	192.9	163.5	200.0
Eye height	139.2	6.4	129.0	139.0	149.9	124.0	161.0
Acromial height	125.0	5.9	116.8	124.3	135.9	112.0	142.0
Elbow height	95.2	4.9	88.0	94.8	103.5	85.0	112.0
Olecranon height	92.5	4.5	85.8	91.5	100.5	84.0	106.0
Waist back length	40.0	3.7	33.3	40.1	46.7	31.5	49.0
Arm reach from the wall	77.9	3.8	72.0	78.0	83.2	65.0	88.0
Waist breadth	31.2	3.3	25.6	31.0	37.0	23.6	38.0
Hip breadth	32.3	3.2	27.0	32.2	38.2	25.0	39.5
Sitting height	76.8	5.5	70.6	77.0	83.9	39.5	88.0
Vertical grip reach sitting	107.4	5.4	97.5	108.0	116.5	91.0	121.0
Sitting eye height	67.6	3.5	61.8	68.0	73.5	58.0	79.0
Sitting acromion height	53.6	3.5	49.0	54.0	60.0	46.0	67.0
Sitting popliteal height	43.6	3.3	38.0	44.0	49.0	33.5	53.0
Knee height sitting	52.2	4.0	45.4	53.0	58.5	34.5	59.0
Thigh clearance	13.1	2.0	10.0	13.0	16.6	8.5	19.0

height sitting							
Elbow rest height	21.4	2.7	16.6	21.5	26.0	13.0	29.0
Buttock knee length	53.1	3.9	47.0	53.2	58.2	37.0	61.3
Buttock popliteal length	45.4	3.4	40.0	45.8	50.0	33.0	56.0
Hip breadth sitting	35.1	5.9	27.3	34.5	47.6	24.0	56.0
Knee-knee breadth	15.0	2.6	11.0	14.5	19.3	10.2	23.0
Shoulder grip length	55.0	4.3	46.9	55.1	61.0	44.2	69.0
Elbow grip length	32.9	4.8	28.0	32.0	41.7	26.5	55.3
Hand length	16.1	1.0	14.5	16.1	17.6	11.7	18.0
Hand breadth at metacarpal III	7.1	0.7	6.2	7.0	8.6	5.7	9.6
Hand breadth across thump	9.9	8.8	7.9	9.0	10.4	7.2	93.0
Palm length	9.0	0.5	8.0	9.0	10.0	7.9	10.5
Grip diameter (inside)	12.1	1.2	10.0	12.0	14.0	9.0	15.0
Foot length	22.1	1.2	20.0	22.0	24.0	18.0	24.7
Foot breadth	7.4	1.8	4.0	8.0	9.5	3.7	10.0
Heel breadth	6.1	1.6	4.0	5.5	9.0	3.2	9.5
Hand grip strength(right)	21.0	5.0	11.3	21.1	29.2	10.0	32.6
Hand grip strength(left)	21.6	5.0	12.8	22.3	29.4	10.0	37.4

(Unit: cm unless otherwise specified)

Ten subjects who are conforming to this statistical requirement was selected. From both tables, it is seen that wide variations are there in most of the body dimension of the subjects. For example, stature of the male subjects varied from 140 to 177 cm with mean value of 163.5 cm. Similar trends were observed in the case of female body dimensions. This wide variation in the body dimension of the subjects is reflected in the high standard deviation of the body dimensions. Also this wide variation is helpful in designing of agricultural devices by taking 5th and 95th per centiles. It is seen that there is a remarkable difference in the body dimensions of male and female workers and the data showed that mean value of body dimension of female workers were lower than the mean body dimensions of male workers. For example, by comparing the mean value of vertical reach and stature of both male and female workers, mean value was higher for males (209.9 cm and 163.5 cm) than females (188.9 cm and 149.5 cm). Grip diameter of the female workers ranged from 9 to 15 cm while for male workers, from 10 and 18 cm.

4.1.2 Medical fitness

The results of the medical investigations carried out for both male and female subjects are furnished in the Table 4.3 and 4.4.

Table 4.3 Bio-clinical analysis report of male subjects

Male						
Sl. No	Items	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
1	Blood group	O	B	B	B	A
2	Rh Factor	negative	positive	positive	positive	positive
3	Haemoglobin (gms per cent)	14	17	16.2	14.8	13.4
4	ESR(mm/1hr)	8	5	5	2	8
5	Blood sugar(R)(mg/dl)	91	101	102	71	101
6	Blood urea(mg/dl)	16	23	23	23	25
7	Cholesterol(mg/dl)	228	196	190	158	206
8	Blood Pressure(mm of Hg)	105/69	140/56	110/70	121/64	119/76
9	Urine sugar	nil	nil	nil	nil	nil
10	Urine albumin	nil	nil	nil	nil	nil
11	ECG	normal	normal	normal	normal	normal

Table 4.4 Bio-clinical analysis report of female subjects

Female						
Sl No	Items	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
1	Blood group	O	B	O	O	O
2	Rh Factor	positive	positive	positive	positive	positive
3	Haemoglobin (gms per cent)	12.6	13.8	12.8	12	10.4

4	ESR(mm/1hr)	7	10	8	5	5
5	Blood sugar(R)(mg/dl)	80	88	70	95	71
6	Blood urea(mg/dl)	12	16	18	13	19
7	Cholesterol(mg/dl)	142	222	230	181	178
8	Blood Pressure(mm of Hg)	95/67	109/63	112/63	111/72	103/61
9	Urine sugar	nil	nil	nil	nil	nil
10	Urine albumin	nil	nil	nil	nil	nil
11	ECG	normal	normal	normal	normal	normal

The results showed that all subjects had normal Electro Cardio Graph (ECG), blood pressure and all the parameters in the bio clinical analysis were within the limit. So, the workers will be able to do work properly without any unusual health problems.

4.2 Calibration of subjects

All the selected subjects (both male and female) were calibrated in laboratory conditions by indirect assessment of oxygen uptake. Sanders and McCormick (1993) suggested the calibration of each person to determine the relationship between heart rate and oxygen consumption.

4.2.1 Basal Metabolic Rate

The basal metabolic rate of the subject was measured by following the procedure explained in section 3.2.3. Sample calculations of both male and female subject were shown below.

a) Computation of BMR (for male subject I)

Age of the subject, years = 36

Weight of subject, kg = 59

Height of subject, m = 1.60

Room temperature (T_2), ° K = 303

Room pressure (P_2), bars = 0.99

Oxygen consumption		
For a period of 6 min (V_2), cc	=	1330
Standard temperature (T_1), ° K	=	273
Standard pressure (P_1), bars	=	1.0325
Oxygen consumed under standard		
Temperature and pressure, lit	=	$\frac{P_2 V_2}{T_2} \times \frac{T_1}{P_1}$
	=	$\frac{0.99 \times 1.330 \times 273}{303 \times 1.0325}$
	=	1.1489
Energy produced in 6 min, kcal	=	1.1489× 4.832
	=	5.552 kcal,
Energy per day, kcal	=	$\frac{5.552 \times 60 \times 24}{6}$
Basal Metabolic Rate, kcal /day	=	1332.46

b) Computation of BMR (for female subject I)

Age of the subject, years	=	35
Weight of subject, kg	=	47
Height of subject, m	=	1.59
Room temperature (T_2), ° K	=	303
Room pressure (P_2), bars	=	0.99
Oxygen consumption		
For a period of 6 min (V_2), cc	=	930
Standard temperature (T_1), ° K	=	273
Standard pressure (P_1), bars	=	1.0325
Oxygen consumed under standard		

Temperature and pressure, lit = $\dfrac{P_2V_2}{T_2} \times \dfrac{T_1}{P_1}$

$$= \frac{0.99 \times 0.930 \times 273}{303 \times 1.0325}$$

= 0.8034

Energy produced in 6 min, kcal = 0.8034 × 4.832

= 3.882 Kcal,

Energy per day, kcal = $\dfrac{3.882 \times 60 \times 24}{6}$

Basal Metabolic Rate, kcal day^{-1} = 931.72

Basal metabolic rate of male subjects ranged from 1051.759 kcal day^{-1} to 2264.18 kcal day^{-1}. For female subjects it ranged from 931.72 kcal day^{-1} to 2063.81 kcal day^{-1}.

4.2.2 Calibration chart

A calibration chart was prepared with heart rate as the ordinate and the oxygen consumption as the abscissa for the selected ten subjects. Astrand and Rodhal (1977) found in their study that there existed a linear relationship between the oxygen consumption and heart rate during calibration. It was observed that the relationship between the heart rate and oxygen consumption of the subjects was found to be linear for all the subjects, which was in close agreement with the results reported by Kromer and Grandjean (2000) and Sam (2014).The calibration chart of both male and female subjects were shown in Fig. 4.1 and 4.2.

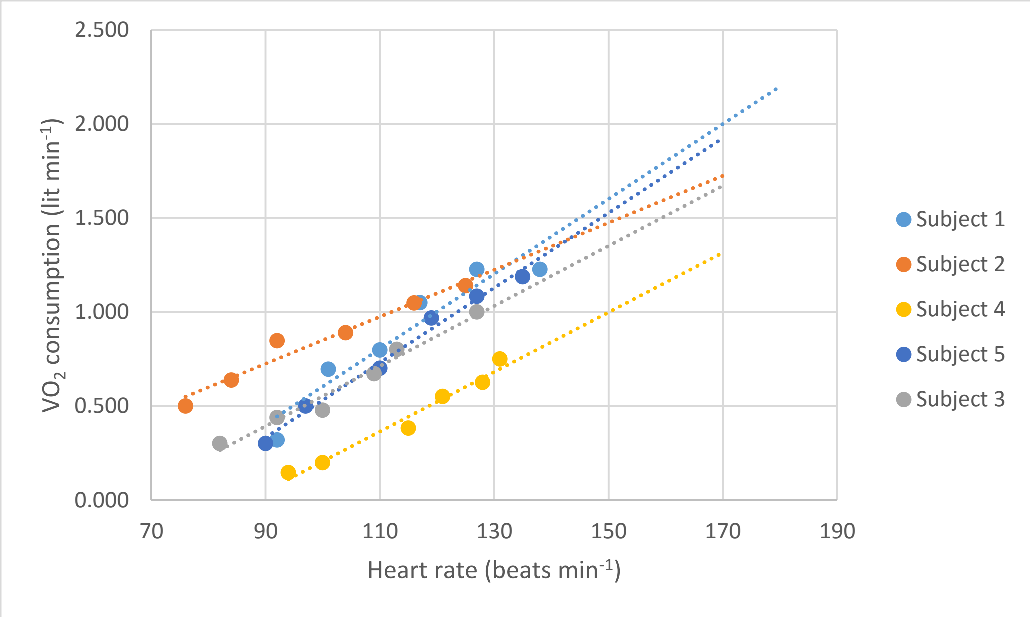


Fig. 4.1 Calibration chart of male subjects

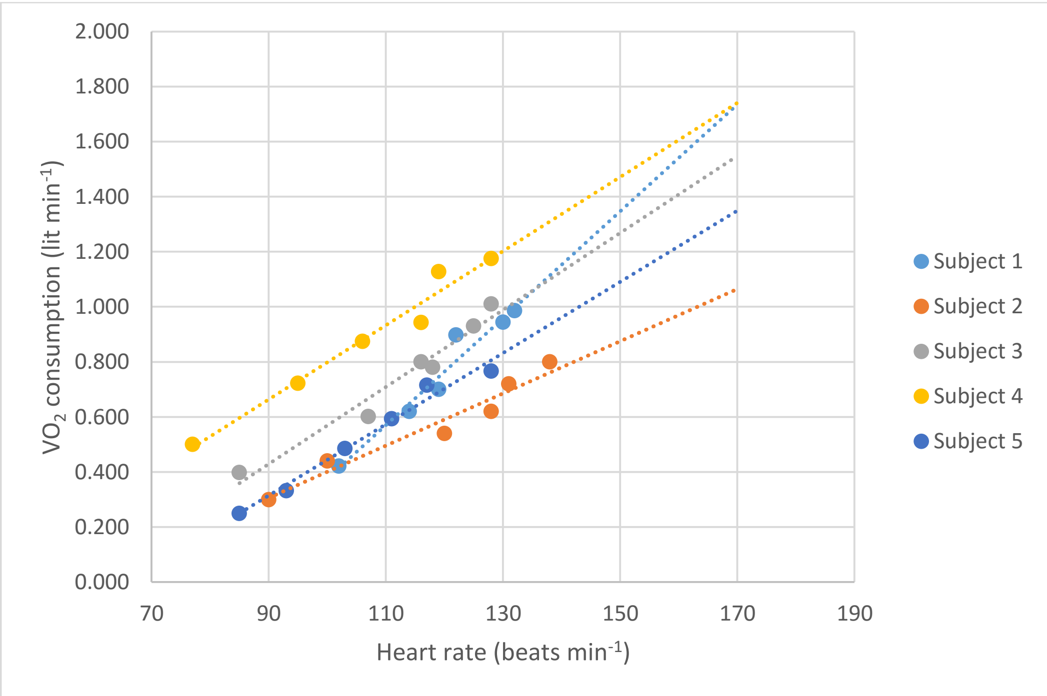


Fig. 4.2 Calibration chart of female subjects

It was observed that for different subjects the linear relationship between heart rate and oxygen consumption was different due to physiological differences of individuals. The relationship between the two parameters oxygen consumption (Y) and heart rate (X) was expressed by the following linear equations.

For Male subject 1, $Y = 0.0199X – 1.3906$ ($R^2 = 0.9079$)

For Male subject 2, $Y = 0.0125X – 0.3988$ ($R^2 = 0.9563$)

For Male subject 3, $Y = 0.0125X – 0.3988$ ($R^2 = 0.9720$)

For Male subject 4, $Y = 0.0158X – 1.3771$ ($R^2 = 0.9705$)

For Male subject 5, $Y = 0.0199X – 1.4611$ ($R^2 = 0.9869$)

For Female subject 1, $Y = 0.0194X – 1.5636$ ($R^2 = 0.9495$)

For Female subject 2, $Y = 0.0095X – 0.5476$ ($R^2 = 0.9501$)

For Female subject 3, $Y = 0.0140X –0.8292$ ($R^2 = 0.9599$)

For Female subject 4, $Y = 0.0135X – 0.5479$ ($R^2 = 0.9667$)

For Female subject 5, $Y = 0.0129X – 0.85$ ($R^2 = 0.9780$)

It showed that the R^2 value was very high for the five male and female subjects selected for this study which means they attained good fit between the oxygen consumption and heart rate.

4.3 Energy cost of operation

The mean heart rate, oxygen consumption and energy cost of each subject was averaged for getting mean value of each coconut climbing device.

4.3.1. Sit and climb type (TNAU model) coconut climbing device

Mean heart rate, oxygen consumption and energy cost of male and female subjects during climbing in Sit and climb type (TNAU model) coconut climbing device was shown in Table 4.5 and 4.6 respectively.

Table 4.5 Mean energy cost of male subjects while operating Sit and climb type (TNAU model) coconut climbing device

Subject	Mean HR (beats min^{-1})	Oxygen consumption (lit min^{-1})	Energy cost (kJ min^{-1})
Subject 1	131.00	1.22	25.40
Subject 2	140.17	1.35	28.26
Subject 3	146.00	1.29	27.01
Subject 4	141.17	0.85	17.82
Subject 5	147.00	1.46	30.57
Mean	**141.07**	**1.24**	**25.81**

The results showed the mean value of energy cost was 25.81 kJ min^{-1} for climbing of Sit and climb type (TNAU model) coconut climbing device. Energy cost was maximum for subject 5 (30.57 kJ min^{-1}) while it was minimum for subject 4 (17.82 kJ min^{-1}).

Table 4.6 Mean energy cost of female subjects while operating Sit and climb type (TNAU model) coconut climbing device

Subject	Mean HR (beats min^{-1})	Oxygen consumption (lit min^{-1})	Energy cost (kJ min^{-1})
Subject 1	162.67	1.59	33.24
Subject 2	169.33	1.06	22.16
Subject 3	142.00	1.16	24.20
Subject 4	162.00	1.64	34.22
Subject 5	147.17	1.05	21.89
Mean	**156.63**	**1.30**	**27.14**

The results showed that energy expended by the female subjects were high while climbing, in comparison with male subjects. The mean energy cost was 27.14 kJ min^{-1} for female subjects.

4.3.2. Standing type (Chemberi model) coconut climbing device

Mean heart rate, oxygen consumption and energy cost of male and female subjects during climbing in Standing type (Chemberi model) coconut climbing device was shown in Table 4.7 and 4.8 respectively

Table 4.7 Mean energy cost of male subjects while operating Standing type (Chemberi model) coconut climbing device

Subject	Mean HR (beats min^{-1})	Oxygen consumption (lit min^{-1})	Energy cost (kJ min^{-1})
Subject 1	125.17	1.10	22.97
Subject 2	142.00	1.38	28.74
Subject 3	145.17	1.28	26.74
Subject 4	135.17	0.76	15.84
Subject 5	138.17	1.29	26.90
Mean	**137.13**	**1.16**	**24.24**

Mean energy cost during the operation of Standing type (Chemberi model) was 24.24 kJ min^{-1} and it ranged from 15.84 kJ min^{-1} to 28.74 kJ min^{-1}. Energy costs of male subjects were less during the operation of Standing type (Chemberi model) compared with Sit and climb type (TNAU model) and decrease was being 6.08 per cent.

Table 4.8 Mean energy cost of female subjects while operating Standing type (Chemberi model) coconut climbing device

Subject	Mean HR (beats min^{-1})	Oxygen consumption (lit min^{-1})	Energy cost (kJ min^{-1})
Subject 1	174.33	1.82	37.97
Subject 2	172.00	1.09	22.68
Subject 3	140.67	1.14	23.81
Subject 4	156.00	1.56	32.53
Subject 5	137.00	0.92	19.15
Mean	**156.00**	**1.30**	**27.23**

The mean value of energy cost while using Standing type (Chemberi model) was 27.23 kJ min^{-1} which was more or less same as that of value obtained for Sit and climb type (TNAU model) coconut climbing device. However it was noted that for subject 5, energy cost was comparatively low during climbing with a value of 19.15 kJ min^{-1} but for subject 1 it looked very high with a value of 37.97 $kJmin^{-1}$.

4.3.3. KAU coconut palm climbing device

Mean heart rate, oxygen consumption and energy cost of male and female subjects during climbing in KAU coconut palm climbing device was shown in the Table 4.9 and 4.10 respectively.

Table 4.9 Mean heart rate, oxygen consumption and energy cost of male subjects while operating KAU coconut palm climbing device

Subject	Mean HR (beats min^{-1})	Oxygen consumption (lit min^{-1})	Energy cost (kJ min^{-1})
Subject 1	127.17	1.14	23.80
Subject 2	139.33	1.34	28.04
Subject 3	137.83	1.16	24.29
Subject 4	135.17	0.76	15.84
Subject 5	130.83	1.14	23.86
Mean	**134.07**	**1.11**	**23.16**

The mean energy cost was comparatively less for the operation of KAU coconut palm climbing device. Mean energy cost during the operation of KAU coconut palm climbing device was 23.16 kJ min^{-1} for male subjects. The energy cost decreased to the tune of 10.26 per cent when compared to Sit and climb type (TNAU model) coconut climbing device.

Table 4.10 Mean energy cost of female subjects while operating KAU coconut palm climbing device

Subject	Mean HR (beats min^{-1})	Oxygen consumption (lit min^{-1})	Energy cost (kJ min^{-1})
Subject 1	162.30	1.67	33.20
Subject 2	165.33	1.02	21.36
Subject 3	135.17	1.06	22.20
Subject 4	152.67	1.51	31.59
Subject 5	135.33	0.90	18.70
Mean	**150.232**	**1.23**	**25.41**

Energy cost of operation of KAU coconut palm climbing device was 25.41 kJ min^{-1} for female subjects. The maximum energy cost was observed to be 33.20 kJ min^{-1} for subject 1 and minimum value was 18.70 kJ min^{-1} for subject 5. The energy costs of the female subjects are higher by 11 per cent compared to male subjects.

4.3.4. Kerasuraksha coconut climbing device

Mean heart rate, oxygen consumption and energy cost of male and female subjects during climbing in Kerasuraksha coconut climbing device was shown in the Tables 4.11 and 4.12 respectively.

Table 4.11 Mean energy cost of male subjects while operating Kerasuraksha coconut climbing device

Subject	Mean HR (beats min^{-1})	Oxygen consumption (lit min^{-1})	Energy cost (kJ min^{-1})
Subject 1	130.67	1.21	25.26
Subject 2	141.17	1.37	28.52
Subject 3	156.17	1.46	30.41
Subject 4	135.00	0.76	15.78
Subject 5	138.83	1.30	27.18
Mean	**140.37**	**1.22**	**25.43**

Mean energy cost during the operation of Kerasuraksha coconut climbing device was 25.43 kJ min^{-1}. Minimum energy cost observed during climbing was 15.78 kJ min^{-1} for subject 4 and the maximum value was 30.41 kJ min^{-1} for subject 3. Energy cost increased by 9.8 per cent during the operation of Kerasuraksha coconut climbing device than KAU coconut palm climbing device.

Table 4.12 Mean energy cost of female subjects while operating Kerasuraksha coconut climbing device

Subject	Mean HR (beats min^{-1})	Oxygen consumption (lit min^{-1})	Energy cost (kJ min^{-1})
Subject 1	168.17	1.70	35.47
Subject 2	171.50	1.08	22.58
Subject 3	140.33	1.14	23.71
Subject 4	159.50	1.61	33.52
Subject 5	150.50	1.09	22.79
Mean	**158.00**	**1.32**	**27.61**

Mean value of energy cost ranged from 22.58 kJ min^{-1} to 35.47 kJ min^{-1}. In the case of female subjects energy cost was more for Kerasuraksha coconut climbing device compared with other models. Energy cost increased to the tune of 7.3 per cent during the operation of Kerasuraksha coconut climbing device than KAU coconut palm climbing device.

4.3.5 CPCRI model coconut climbing device

Mean heart rate, oxygen consumption and energy cost of male and female subjects while operating in CPCRI model coconut climbing device was shown in the Tables 4.13 and 4.14 respectively.

Table 4.13 Mean energy cost of male subjects while operating CPCRI model coconut climbing device

Subject	Mean HR (beats min^{-1})	Oxygen consumption (lit min^{-1})	Energy cost (kJ min^{-1})
Subject 1	124.50	1.09	22.70
Subject 2	149.00	1.46	30.56
Subject 3	142.50	1.24	25.85
Subject 4	134.67	0.75	15.67
Subject 5	137.33	1.27	26.56
Mean	**137.60**	**1.16**	**24.27**

Mean energy cost during the operation of CPCRI model coconut climbing device was 24.27 kJ min^{-1}. Energy cost was maximum for subject 2 while it was minimum for subject 4. Energy cost was decreased by 6 per cent during the operation of this model than Sit and climb type (TNAU model) coconut climbing device.

Table 4.14 Mean energy cost of female subjects while operating CPCRI model coconut climbing device

Subject	Mean HR (beats min^{-1})	Oxygen consumption (lit min^{-1})	Energy cost (kJ min^{-1})
Subject 1	163.67	1.61	33.65
Subject 2	168.67	1.05	22.02
Subject 3	143.17	1.18	24.54
Subject 4	153.00	1.52	31.69
Subject 5	141.67	0.98	20.41
Mean	**154.03**	**1.27**	**26.46**

Mean energy cost of operation of CPCRI model coconut climbing device was 26.46 kJ min^{-1} for female operators and it ranged from 20.14 kJ min^{-1} to

33.65 kJ min^{-1}. In the case of female subjects energy cost was decreased by 3.9 percent than Kerasuraksha coconut climbing device.

The heart rate during operation of selected 5 models of coconut climbing devices was also compared. Mean heart rate and energy cost of male subjects during coconut climbing are shown in the Fig. 4.3.

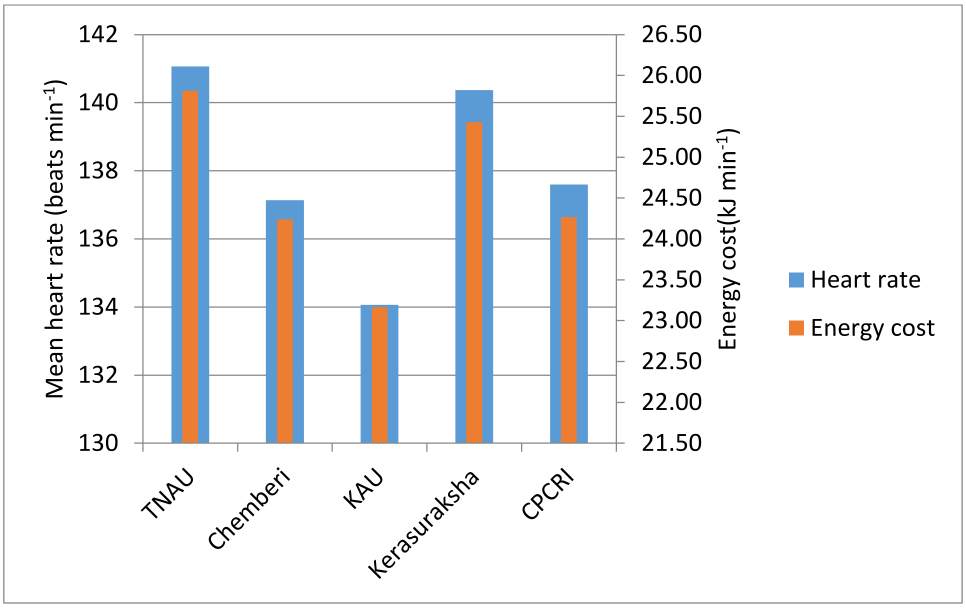


Fig. 4.3 Mean heart rate and energy cost of male subjects during coconut climbing

It was quite clear from the Fig. 4. 3 that the mean heart rate for Sit and climb type (TNAU model) and Kerasuraksha coconut climbing device was very high with a value of 141.06 beats min^{-1} and 140.36 beats min^{-1} respectively and it was minimum for KAU coconut palm climbing device with 134.06 beats min^{-1}. The percentage increase of heart rate was 5.2 per cent. Mean heart rate for Chemberi and CPCRI model coconut climbing device shows the value of 137.13 beats min^{-1} and 137.6 beats min^{-1} respectively. It is clear that energy cost also showed similar trend of heart rate. The TNAU model showed highest energy cost while KAU coconut palm climbing device had lowest value.

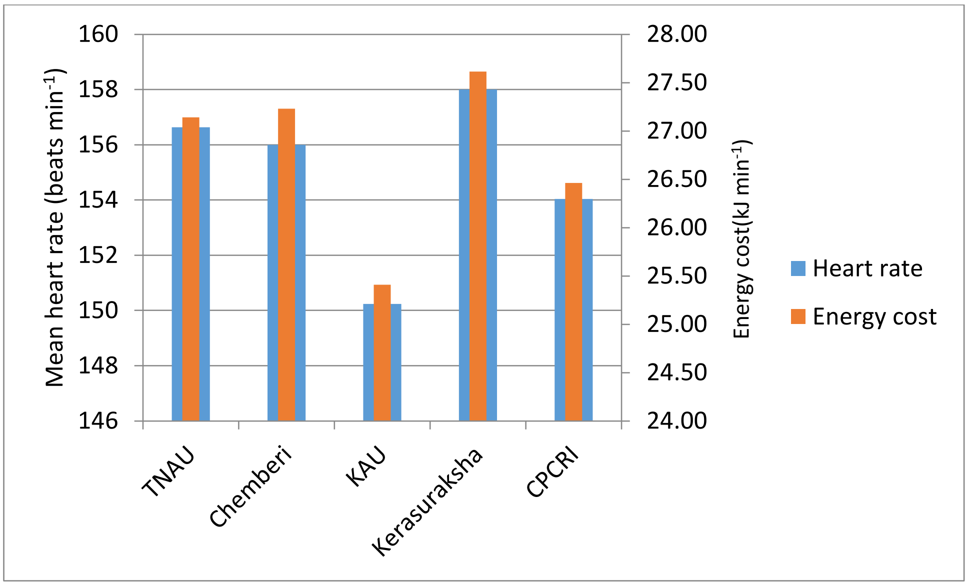


Fig. 4.4 Mean heart rate and energy cost of female subjects during coconut climbing

It was seen from the Fig. 4.4 that both heart rate and energy cost of female while operating coconut climbing device had same trend and maximum observed while operating Kerasuraksha coconut climbing device (158 beats min^{-1} and 27.61 kJ min^{-1} respectively) for female subjects than other models during climbing and minimum heart rate is observed for KAU coconut palm climbing device (150.23 beats min^{-1} and 25.41 kJ min^{-1} respectively) in comparison with other four models. Mean heart rate for TNAU, Chemberi and CPCRI model coconut climbing device were 156.33, 156 and 154.03 beats min^{-1} respectively. Heart rate of female has increased at a rate of 4.6 per cent from KAU coconut palm climbing device to Kerasuraksha coconut climbing device.

4.4 Statistical analysis of heart rate and energy cost

Variation of heart rate and energy cost of both male and female for selected five models were statistically analyzed and were given in the Tables 4.15, 4.16, 4.17 and 4.18 respectively.

Table 4.15 Variation of average heart rate (beats min^{-1}) of male subjects while operating different models

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
TNAU	131.000^{b}	140.167^{a}	146.000^{a}	141.167^{a}	147.000^{b}
Chemberi	125.167^{ab}	142.000^{a}	145.167^{a}	135.167^{a}	138.167^{ab}
KAU	127.167^{ab}	139.333^{a}	137.833^{a}	135.167^{a}	130.833^{a}
Kerasuraksha	130.667^{ab}	141.167^{a}	156.167^{a}	135.000^{a}	138.833^{ab}
CPCRI	124.500^{a}	147.000^{a}	142.500^{a}	134.667^{a}	137.333^{ab}

The results of the study show that significant difference in heart rate was noticed only in TNAU model and CPCRI model for subject 1. Heart rate while operating TNAU model shows superior value over other models and minimum heart rate was found in CPCRI model coconut climbing device. In case of subject 5 a significant difference in heart rate was noticed in TNAU model and KAU coconut palm climbing device. Maximum heart rate was observed in TNAU model and minimum heart rate was in KAU coconut palm climbing device. In the case of subject 2, subject 3 and subject 4 there was no significant difference between heart rate while operating different models but it was seen that these subjects shows less heart rate for KAU coconut palm climbing device.

Table 4.16 Variation of average heart rate (beats min^{-1}) of female subjects while operating different models

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
TNAU	162.667^{a}	169.333^{a}	142.000^{b}	162.000^{c}	147.167^{c}
Chemberi	174.333^{b}	172.000^{a}	140.667^{ab}	156.000^{ab}	137.000^{ab}
KAU	162.333^{a}	165.333^{a}	135.167^{a}	152.667^{a}	135.333^{a}
Kerasuraksha	168.167^{ab}	171.500^{a}	140.333^{ab}	159.500^{bc}	150.500^{c}
CPCRI	163.667^{a}	168.667^{a}	143.167^{b}	153.000^{a}	141.667^{b}

It is quite evident from the result that all female subjects were significantly differed in heart rate on different coconut climbing devices except subject 2 and all the female subjects showed minimum heart rate while operating KAU coconut palm climbing device.

Table 4.17 Variation of average energy cost (kJ min^{-1}) of male subjects while operating different models

	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
TNAU	25.396[a]	28.257[a]	27.015[a]	17.818[a]	30.572[b]
Chemberi	22.973[a]	28.735[a]	26.736[a]	15.838[a]	26.902[ab]
KAU	23.804[a]	28.039[a]	24.286[a]	15.838[a]	23.855[a]
Kerasuraksha	25.258[a]	28.518[a]	30.411[a]	15.783[a]	27.179[ab]
CPCRI	22.696[a]	30.040[a]	25.845[a]	15.673[a]	26.556[ab]

It is visible that only subject 5 shows significant difference in energy cost in TNAU model and KAU model while analyzing the effect of different models of coconut climbing devices on energy cost for male subjects. There was no significant variation in heart rate with different models of coconut climbing devices for subject 1, subject 2, subject 3 and subject 4.

Table 4.18 Variation of average energy cost (kJ min^{-1}) of female subjects while operating different models

	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]	32.533a[b]	19.153[ab]
KAU	33.109[a]	21.362[a]	22.198[a]	31.594[a]	18.704[a]
Kerasuraksha	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]

Similar results are observed (Table 4.16) while analyzing the effect of different models of coconut climbing devices on energy cost for female subjects. Statistical analysis showed that there was significant difference in energy cost for all female subjects at except subject 2 at 5 per cent level of probability. Energy cost was recorded significantly lower in KAU coconut climbing device.

4.5 Grading of work

Based on the physiological response of the workers during climbing in different models of coconut climbing devices, the work was classified in accordance with Sen (1969) classification as explained in the section 2.2.6. Table 4.19 and 4.20 show the grading of work of both male and female workers.

Table 4.19 Grade of work of male subjects during climbing operation

Selected model	Grade of work
TNAU Model	Heavy
Chemberi Model	Heavy
KAU Model	Heavy
Kerasuraksha	Heavy
CPCRI model	Heavy

It is observed from the table that in the case of male subjects grade of work was same for all the models and it was graded as "Heavy". It ranged between 125 – 150 beats min^{-1} for Heavy work .

Table 4.20 Grade of work of female subjects during climbing operation

Selected model	Grade of work
TNAU Model	Very Heavy
Chemberi Model	Very Heavy
KAU Model	Very Heavy
Kerasuraksha	Very Heavy
CPCRI model	Very Heavy

Similar trend was observed in the case of female operators. For all models it was graded as "Very Heavy" work since value was between 150 -175 beats min^{-1}.

4.6 Acceptable work load

The acceptable workload (AWL) for Indian workers was the work consuming 35 per cent of VO_2 max (Saha *et al*., 1979).

4.6.1 Maximum aerobic capacity

Maximum aerobic capacity of each subject was determined from the calibration chart as explained in section 3.4.2.1. Table 4.21 and 4.22 shows the maximum aerobic capacity of male and female subjects respectively.

Table 4.21 Maximum aerobic capacity of male subjects

Subjects	Maximum heart rate (beats min^{-1})	Maximum aerobic capacity (lit min^{-1})
Subject 1	176.60	2.12
Subject 2	183.10	1.89
Subject 3	181.80	1.87
Subject 4	184.40	1.54
Subject 5	176.60	2.05
Mean	180.50	1.90

Table 4.22 Maximum aerobic capacity of female subjects

Subjects	Maximum heart rate (beats min^{-1})	Maximum aerobic capacity (lit min^{-1})
Subject 1	186.35	2.05
Subject 2	179.20	1.15
Subject 3	185.05	1.76
Subject 4	180.50	1.89
Subject 5	177.25	1.44
Mean	181.67	1.66

Maximum aerobic capacity of male subjects varied from 1.54 to 2.12 lit min^{-1} and for female subjects it varied from 1.44 to 2.05 lit min^{-1}. These values conformed to the results of other investigations where values ranged from 1.5 to 2.5 lit min^{-1} (Sivakumar, 2001). The mean oxygen consumption in terms of maximum aerobic capacity with respect to all selected models was calculated and presented in Table 4.23 and 4.24.

Table 4.23 Oxygen consumption in terms of VO_2 max of male subjects in coconut climbing operation

Model	Mean VO_2	Oxygen consumption in terms of VO_2 Max (per cent)	AWL (35 per cent of VO_2 max)
TNAU	1.24	65.22	> AWL
Chemberi	1.16	61.24	> AWL
KAU	1.11	58.53	> AWL
Kerasuraksha	1.22	64.26	> AWL
CPCRI	1.16	61.32	> AWL

Table 4.24 Oxygen consumption in terms of VO_2 max of female subjects in coconut climbing operation

Model	Mean VO_2	Oxygen consumption in terms of VO_2 Max (per cent)	AWL (35 per cent of VO_2 max)
TNAU	1.30	78.37	> AWL
Chemberi	1.30	78.62	> AWL
KAU	1.23	74.30	> AWL
Kerasuraksha	1.32	79.74	> AWL
CPCRI	1.27	76.41	> AWL

It is observed that the all the values were much higher than that of the AWL limits of 35 per cent indicating that all the selected operations could not be operated continuously for 8 hours without frequent rest-pauses. The oxygen consumption in terms of VO_2 max was minimum for KAU coconut palm climbing device for both male and female operators and the values were 58.53 per cent and 74.30 per cent respectively. The maximum VO_2 max was observed to be 65.22 per cent for TNAU model for male operators and 79.74 per cent for Kerasuraksha coconut climbing device for female operators. The oxygen consumption in terms of VO_2 max was higher for females comparing with males.

4.7 Limit of continuous performance

Work pulse is the difference between working pulse and resting pulse. The average values of the heart rate at rest level and at working condition were used for calculating resting pulse and working pulse. Work pulse of male and female subjects while operating selected coconut climbing devices were given in the Table 4.25 and 4.26.

Table 4.25 Work pulse of male subjects for selected coconut climbing devices

Selected Model	**Work pulse (Δ HR), beats min^{-1}**	**LCP (40 beats min^{-1})**
TNAU	77.27	>LCP
Chemberi	73.33	>LCP
KAU	70.27	>LCP
Kerasuraksha	76.57	>LCP
CPCRI	73.80	>LCP

It is observed that in all the selected operations, the work pulse values were well above the limit of continuous performance of 40 beats min^{-1}, which indicates that workers could not operate the coconut climbing device continuously for 8-h duration. The maximum value of work pulse for Sit and climb type (TNAU model) was 77.27 beats min^{-1} and the minimum value of work pulse was for KAU coconut palm climbing device (73.33 beats min^{-1}).

Table 4.26 Work pulse of female subjects for selected coconut climbing devices

Selected Model	**Work pulse (Δ HR), Beats min^{-1}**	**LCP (40 beats min^{-1})**
TNAU	87.23	>LCP
Chemberi	86.60	>LCP
KAU	81.60	>LCP
Kerasuraksha	88.60	>LCP
CPCRI	84.63	>LCP

It is clear that for all selected coconut climbing devices the work pulse was greater than 40 beats min^{-1} during climbing operation. So, female subjects also could not operate the coconut climbing device continuously for 8-h duration. The value of work pulse of female subjects during climbing was high in comparison with male subjects. The value of work pulse during climbing varied from 81.60 beats min^{-1} to 88.60 beats min^{-1}. The maximum work pulse was for Kerasuraksha coconut climbing device while the minimum work pulse was for KAU coconut palm climbing device.

4.8 Time requirement

Time taken during climbing up and down in each selected coconut climbing device was shown in Fig. 4.5 and Fig. 4.6 for male and female subjects.

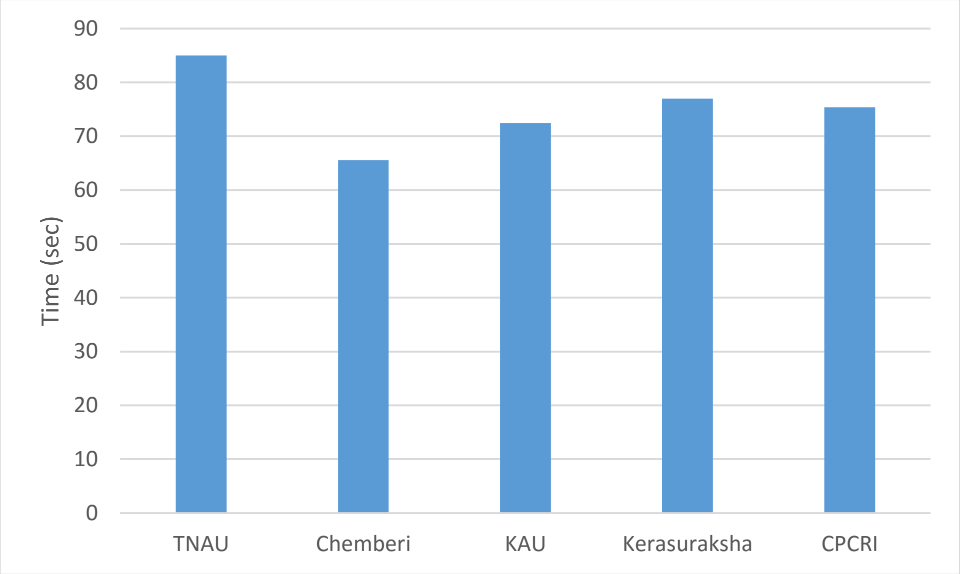


Fig. 4.5 Time needed for male subjects in using each coconut climbing device

It was observed that male subject took more time (84.98 sec) for climbing in TNAU model and minimum time (65.56 sec) was taken for operating Standing type (Chemberi model). Time taken to operate KAU coconut palm climbing device was 72.46 sec.

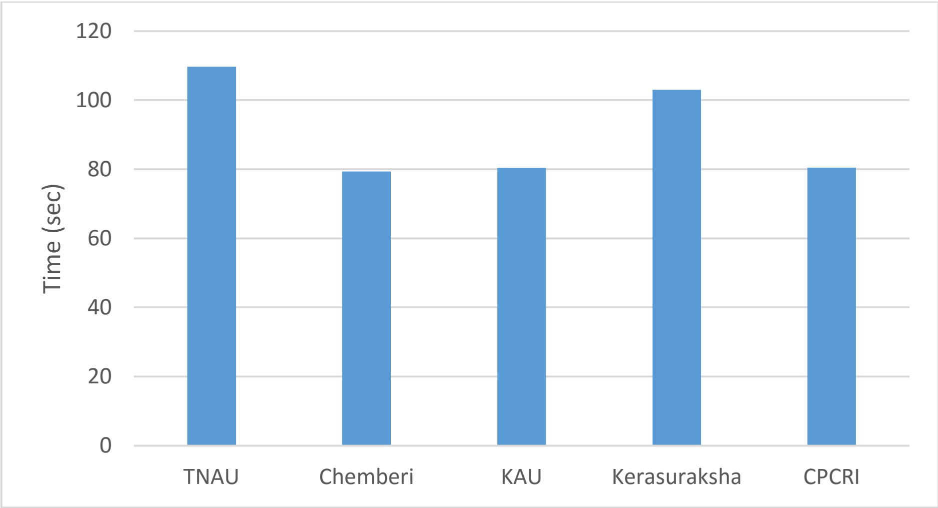


Fig. 4.6 Time needed for female subjects in using each coconut climbing device

In Fig. 4.6 it was clear that time needed for operating coconut climbing devices such as KAU coconut palm climbing device, Standing type (Chemberi model) and CPCRI model coconut climbing device was more or less same and was comparatively less than the other two models. Maximum time was taken for operating Sit and climb type (TNAU model) (109.69 sec) and minimum for Standing type (Chemberi model) with the time duration of 79.35 sec for female subjects.

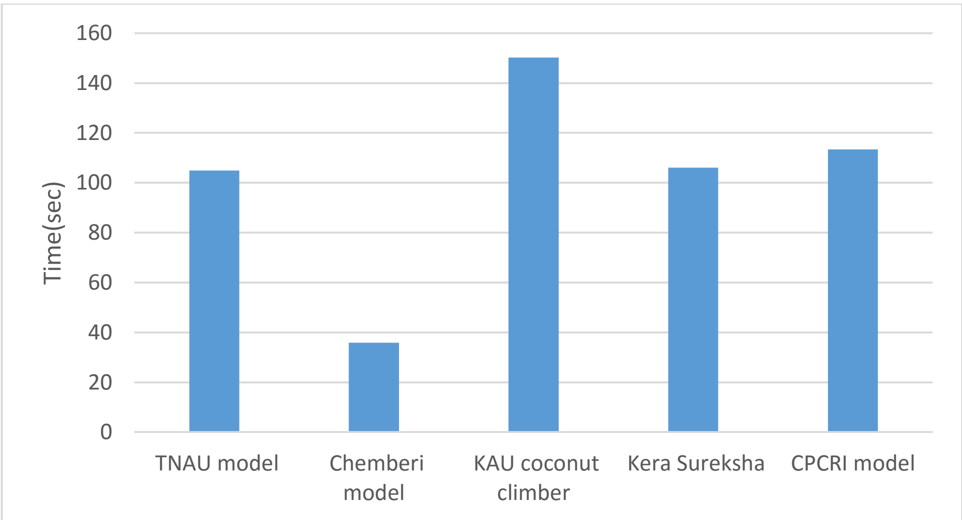


Fig. 4.7 Setting time for each coconut climbing device

It was seen that setting time needed for KAU coconut palm climbing device was very much higher than that of other four models and it took about 150 seconds. But for Standing type (Chemberi model), the setting time was very less compared with other models. Time for setting of Chemberi model was about 35 seconds.

4.9 Subjective rating scales

Ergonomic evaluation of the five selected coconut climbing devices was done and each subject were asked to rate those models according to ease of operation, comfortability, safety and pain of body parts. The data were averaged for getting mean score of each model. The mean score of ODR, OER, OSR and BPDS for male and female subjects are presented in the following Tables 4.27, 4.28, 4.29 and 4.30

Table 4.27 Overall Discomfort Rating of selected coconut climbing devices

Model		Male	Female
TNAU	Score	4.2	5.8
	Scale	>Light discomfort	>Moderate discomfort
Chemberi	Score	1.8	3
	Scale	>No discomfort	Light discomfort
KAU	Score	3	3
	Scale	Light discomfort	Light discomfort
Kerasuraksha	Score	4.2	3.8
	Scale	>Light discomfort	>Light discomfort
CPCRI	Score	3.4	4.6
	Scale	>Light discomfort	>Light discomfort

It is observed that discomfort rate was high for Sit and climb type (TNAU model) and Kerasuraksha coconut climbing device with the score of 4.2 for male subjects and it was scaled as “ > Light discomfort”. In the case of female subjects discomfort was more for Sit and climb type (TNAU model) and it scored 5.8. The high discomfort score of Sit and climb type (TNAU model) was because of its heavy weight. CPCRI model coconut climbing device also high score of 4.6 for female and 3.4 for male subjects with the scale of “Light discomfort”. It might have been due to the jacket provided to the machine which makes the discomfort, especially for female workers. The discomfort level of Standing type (Chemberi model) and KAU coconut palm climbing device were comparatively less.

Table 4.28 Overall Safety Rating (OSR) of selected coconut climbing devices

Model		Male	Female
TNAU	Score	2.8	5.2
	Scale	>Secure and meager fear	>Moderately secure and less fear
Chemberi	Score	4	5.2
	Scale	Moderately secure and less fear	>Moderately secure and less fear
KAU	Score	1.6	2.8
	Scale	>Completely secure and no fear	>Secure and meager fear
Kerasuraksha	Score	2.8	3.2
	Scale	>Secure and meager fear	>Secure and meager fear
CPCRI	Score	2.8	2
	Scale	>Secure and meager fear	Secure and meager fear

It was seen that the safety was less for Standing type (Chemberi model) with scale as “Moderately secure and less fear” and showed the score of 4 by male subjects and 5.2 for female subjects. Female subjects also showed the score of 5.2 with the scale of “Secure and meagre fear” for TNAU model, that might be due to its heavy weight. CPCRI model coconut climbing also show scale as “Secure and meagre fear” with the score of 2.8 by male and 2 by female subjects. The safety rating was comparatively less for KAU coconut palm climbing device and CPCRI model coconut climbing device for both male and female subjects which means these two models were comparatively safe during operation.

Table 4.29 Overall Ease of Operation Rating (OER) of selected coconut climbing devices

Model		Male	Female
TNAU	Score	4.4	7.2
	Scale	>Less difficulty	>Difficult to operate
Chemberi	Score	2	2.8
	Scale	Easy	>Easy
KAU	Score	1.6	2.4
	Scale	>Very easy	>Easy
Kerasuraksha	Score	3.6	4
	Scale	>Easy	Less difficulty
CPCRI	Score	3.2	4.4
	Scale	>Easy	>Less difficulty

The result showed that Sit and climb type (TNAU model) was found difficult to operate compared with other devices for both male and female subjects. It showed score of 4.4 and 7.2 for male and female respectively. In the case of KAU Model and Chemberi model the rating on ease was comparatively less with scores between1.6 and 2.8 for both male and female.

Table 4.30 Body Part Discomfort Score of selected coconut climbing devices

Model	**Male**	**Female**
TNAU	32.1	35.7
Chemberi	28.2	28.5
KAU	26.1	26.4
Kerasuraksha	27.4	27
CPCRI	27	29.1

It was observed that body part discomfort was different for different coconut climbing devices. Most of the discomfort happened in left thigh, right thigh, left foot and right foot. In Sit and climb type (TNAU model) and Kerasuraksha coconut climbing device the whole leg portion(lower frame) has to be lifted up by front portion of the foot, that gave subjects more pain in foot and skin was getting irritated. Also in the case of Sit and climb type (TNAU model) weight was too high and that made it more uncomfortable especially for female workers. Seating of KAU coconut palm climbing device and Sit and climb type (TNAU model) lead to back pain due to the lack of back supporting structure and made rashes on thigh portion because of the material of the seat. But comparing with other models KAU coconut palm climbing device was more comfortable for subjects because of the specially designed shoes which gave good feel to operate. Similarly, in the case of Kerasuraksha 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 lower portion was uncomfortable and for CPCRI model coconut climbing device the jacket increased this problem. Body Part Discomfort Score was maximum for Sit and climb type (TNAU model) (32.1 and 35.7) while it was minimum for KAU coconut palm climbing device (26.1 and 26.4) for both male and female.

4.10 Modification

Based on the above evaluations it was found that KAU coconut palm climbing device and Kerasuraksha coconut climbing device were more suitable for climbers than other climbing devices. The study revealed that seating unit of Kerasuraksha coconut climbing device and pedal unit of KAU coconut palm climbing device were ergonomically comfortable for the climbing operator. Hence KAU coconut palm climbing device and Kerasuraksha coconut climbing device were selected for ergonomic refinements and a new model was developed by incorporating the constructional behavior of both KAU coconut palm climbing device and Kerasuraksha coconut climbing device and incorporated changes are described in section 3.7.

4.11 Evaluation of the New model

4.11.1 Energy cost of operation

Mean heart rate, oxygen consumption and energy cost of male and female subjects while operating new model coconut climbing device was shown in the Table 4.31 and 4.32 respectively

Table 4.31 Mean energy cost of male subjects while operating new model coconut climbing device.

Subject	**Mean HR (beats min^{-1})**	**Oxygen consumption (lit min^{-1})**	**Energy cost (kJ min^{-1})**
Subject 1	127.50	1.15	23.94
subject 2	136.50	1.31	27.30
Subject 3	138.00	1.17	24.34
Subject 4	135.00	0.76	15.78
Subject 5	130.50	1.14	23.72
Mean	**133.50**	**1.10**	**23.02**

It was visible that mean energy cost of new model was 23.02 kJ min^{-1} for male operators. It ranged from minimum value of 15.78 kJ min^{-1} and maximum value of 27.30 kJ min^{-1}. Energy cost decreased by the rate of 10.8 per cent when compared to Sit and climb type (TNAU model) and with KAU coconut palm climber it was comparable Also energy reduced to the tune of 9.4 per cent with Kerasuraksha coconut climbing device.

Table 4.32 Mean energy cost of female subjects while operating new model coconut climbing device

Subject	**Mean HR (beats min^{-1})**	**Oxygen consumption (lit min^{-1})**	**Energy cost (kJ min^{-1})**
Subject 1	154.50	1.43	29.94
subject 2	157.50	0.95	19.81
Subject 3	145.50	1.21	25.22
Subject 4	155.50	1.55	32.39
Subject 5	139.50	0.95	19.83
Mean	**150.50**	**1.22**	**25.44**

Mean energy cost of new model for female worker was 25.44 kJ min^{-1}. The minimum energy cost was 19.81 kJ min^{-1}, for subject 2 and maximum was for subject 4 with value of 32.39 kJ min^{-1}. Energy cost of new model was decreased by 7.8 per cent with Kerasuraksha coconut climbing device and 6.2 per cent with Sit and climb type (TNAU model) and it was comparable with KAU coconut palm climber.

4.11.2 Other ergonomic parameters

Table 4.33 shows other ergonomic parameters obtained for new model coconut climbing device.

Table 4.33 Other ergonomic parameters of new model

Parameters	Male	Female
Mean VO_2(lit min$^{-1)}$	1.10	1.22
Oxygen consumption in terms of VO_2 Max (per cent)	58.16	73.45
AWL (35 per cent of VO_2 max)	>AWL	>AWL
Work pulse (Δ HR), beats min^{-1}	69.70	81.10
LCP (40 beats min^{-1})	>LCP	>LCP
Grade of work	Heavy	Very heavy

It was visible that mean VO_2 and Oxygen consumption in terms of VO_2 max of new model was 1.10 lit min^{-1} and 58.16 per cent for male and for female, it was 1.22 and 73.45 per cent respectively. These values were comparatively less than the value observed for other five models. Work pulse of new model was also less than the values of selected other five models for both male and female subjects. It was also seen from the table that, both acceptable work load and LCP is not within the limit as found in earlier climbing machines for both male and female operators. So, the machine could not be operated continuously for 8 hours without frequent rest-pauses. New model was graded as Heavy for male subjects and Very Heavy for female. It is seen that similar trend was observed for other selected five coconut climbing devices.

4.11.4 Time requirement and Setting time

The time required for climbing new model was 65.01 sec for male subjects, which is less than other five selected coconut climbing devices and same for female also. Female subjects were also took less time of 75.51 sec to climb with new model when compared with other models. The setting time of the new model was 65 sec while for KAU coconut palm climber it was 150 sec. Time was reduced by 56.67 per cent compared to KAU coconut palm climber.

4.11.4 Subjective rating scale

Table 4.34 Subjective rating scale of new model

Parameter	Male		Female	
	Score	Scale	Score	Scale
ODR	3.4	> Light discomfort	3.8	> Light discomfort
OSR	2.8	> Secure and meager fear	2.8	> Secure and meager fear
OER	2	Easy	2.4	> Easy
BPDS	25.2	-	27.9	-

The overall discomfort score was 3.4 and 3.8 respectively for male and female subjects and rating was more than light discomfort. Overall safety rating was more than secure and meager fear for both female and male with a value of 2.8 and rated easy for Overall Ease of Rate. Compared with other five operating models new developed model is far better during operation and with reduced weight of 7.9 Kg. Body Part Discomfort Score was 25.2 and 27.9 for male and female respectively.

Summary and Conclusion

CHAPTER 5

SUMMARY AND CONCLUSIONS

Skilled workers can climb the coconut tree for harvesting coconuts, nevertheless it is dangerous to climb very tall coconut trees in which minute carelessness may result in severe injury. Also the workers employed for climbing suffer from physical strain and musculoskeletal disorders. In order to overcome all these several coconut climbing devices were developed. However safety and efficiency aspects were not studied for these equipments. An ergonomically designed equipment not only minimize drudgery of the labor but also increase productivity at reduced expenditure levels**.** Thus an ergonomic evaluation was conducted on five selected most common coconut climbing devices and suitable modifications were made so as to develop a more user-friendly climbing device.

5.1 Ergonomic evaluation of selected coconut climbing devices

An anthropometric survey was conducted in three zones all over the Kerala to select the subjects for the study. From these each zone a sample of 60 subjects were selected with equal representation to men and women. Pertinent anthropometric dimensions of human subjects with reference to the dimensions and positions of the functional components of coconut climbing devices were identified and 35 different body dimensions useful for the design or redesign of coconut climbing devices selected for the study were recorded by following standard anthropometric procedure. Ten subjects (five each for men and women) were selected, who had anthropometric dimensions conforming to statistical requirements and screened for normal health by medical investigations. All the subjects were calibrated in the laboratory to determine the relationship between heart rate and oxygen uptake. The oxygen consumption of the subjects was measured with the Benedict- Roth Recording Spirometer and the heart rate using Polar heart rate monitor. The experiments were conducted in FSRS farm. Five coconut climbing device were selected, those are Sit and climb type (TNAU model), Standing type (Chemberi model), KAU coconut palm climber (developed at KCAET), Kerasureksha (Model developed at ARS, Mannuthy) and CPCRI model coconut climbing device. All the subjects were given equal training on the operations of all coconut climbing devices until they got acquainted with the operations. A 30 minutes rest was recommended for the subjects before the starting of each trial. The heart rate of the subject was measured continuously till subjects got a normal and steady heart rate. Heart rate was measured for each selected model and each trial was replicated three times. From the values of heart rate (HR) observed during the trials, the corresponding values of oxygen consumption rate (VO_2) of the subjects for all the selected coconut climbing device were predicted from the calibration chart of the subjects. The energy cost of selected coconut climbing devices were computed by multiplying the oxygen consumed by the subject during the trial period with the calorific value of oxygen as 20.88 kJ/lit for all the subjects.

i) Basal metabolic rate of male subjects ranged from 1051.759 kcal day^{-1} to 2264.18 kcal day^{-1}. For female subjects it ranged from 931.72 kcal day^{-1} to 2063.81 kcal day^{-1}.

ii) The selected ten subjects were calibrated in the laboratory by indirect assessment of oxygen uptake. The relationship between the heart rate and oxygen consumption of the subjects was found to be linear for all the subjects.

iii) The maximum aerobic capacity was higher for male subjects than female subjects. Maximum aerobic capacity of male subjects varied from 1.54 to 2.12 lit min^{-1} while for female subjects it was from 1.44 to 2.05 lit min^{-1}.

iv) The mean heart rate, oxygen consumption and energy cost were averaged for getting mean value for climbing of each coconut climbing device

v) For male subjects, the mean heart rate for Sit and climb type (TNAU model) was very high with a value of 141.06 beats min^{-1} and mean heart rate was minimum for KAU coconut palm climber with 134.06 beats min^{-1} during climbing operation.

vi) In the case of female subjects, during climbing operation the mean heart rate Standing type (Chemberi model) was very high and mean heart rate was minimum for KAU coconut palm climber.

vii) The mean value of energy cost of Sit and climb type (TNAU model) during climbing operation was 25.81 kJ min^{-1} for male operators while energy cost of female was 27.14kJ min^{-1}.

viii) Mean energy cost of male subjects during the operation of Standing type (Chemberi model) was 24.24 kJ min^{-1} but for female, it was 27.23 kJ min^{-1} for climbing up and climbing down respectively.

ix) Energy cost was comparatively less for KAU coconut palm climber with other models. Mean energy cost of male subjects during the operation of KAU coconut palm climber was 23.16 kJ min^{-1} and for female was 25.41 kJ min^{-1}.

x) Mean value of energy cost of female ranged from 22.58 kJ min^{-1} to 35.47 kJ min^{-1} for Kerasuraksha coconut climbing device. Mean energy cost of male operator was 25.43 kJ min^{-1}.

xi) Energy cost of operation of CPCRI model coconut climbing device for female subject was 26.46 kJ min^{-1}. Mean energy cost of male subjects was 24.27kJ min^{-1}.

xii) In the case of statistical analysis of heart rate for male subjects, significant difference in heart rate was noticed only in TNAU model and CPCRI model for subject 1. Heart rate while operating TNAU model shows superior value over other models and minimum heart rate was found in CPCRI model coconut climbing device. In case of subject 5 a significant difference in heart rate was noticed in TNAU model and KAU coconut palm climbing device.

xiii) Only subject 5 showed significant difference in energy cost in TNAU model and KAU model while analysing the effect of different models of coconut climbing devices on energy cost for male subjects. There was no significant variation in heart rate with different models of coconut climbing devices for subject 1, subject 2, subject 3 and subject 4.

xiv) Female subjects significantly differed in heart rate on different coconut climbing devices except subject 2 and all the female subjects showed minimum heart rate while operating KAU coconut palm climbing device. Similar trend was observed for energy cost of female subjects while operating five different model.

xv) For male subjects climbing operation was “Heavy” work in all models while in the case of female subjects climbing was “Very heavy” work.

xvi) The oxygen consumption in terms of VO_2 max was minimum for KAU coconut palm climber (58.53 per cent) while it was 65.22 per cent for TNAU and 64.26 per cent for Kerasuraksha coconut climbing devices for male operators. Similarly for female subjects, the highest value was for Kerasuraksha coconut climbing device (79.74 per cent) and minimum for KAU coconut palm climber (74.30 per cent). The value of oxygen consumption in terms of VO_2 max was higher for females compared to males.

xvii) Male subject took more time (84.98 sec) for climbing in TNAU model and minimum time (65.56 sec) was taken for operating Standing type (Chemberi model). For female subjects, KAU coconut palm climber, Standing type (Chemberi model) and CPCRI model coconut climbing device was more or less same and was comparatively less than other two models.

xviii) Setting time needed for KAU coconut palm climber was very much higher than that of other four models and it took about 150 seconds. But for Standing type (Chemberi model) the setting time was very less compared with other models. Time for setting of Chembri model was only about 35 seconds.

xix) Discomfort rate was high for Sit and climb type (TNAU model) and Kerasuraksha coconut climbing device with the score of 4.2 for male subjects and it was scaled as “ > Light discomfort”. In the case of female subjects discomfort was more for Sit and climb type (TNAU model) and it scored as 5.8.

xx) The overall safety rating indicate that Standing type (Chemberi model) was less safe than other models with scale as "Moderately secure and less fear" and had the score of 4 by male subjects and 5.2 for female subjects.

xxi) Sit and climb type (TNAU model) was difficult in operation compared with other devices. It had score of 4.4 and 7.2 for male and female respectively.

xxii) Body Part Discomfort Score was maximum for Sit and climb type (TNAU model) (32.1 and 35.7) while it was minimum for KAU coconut palm climbing device (26.1 and 26.4) for both male and female. Majour discomfort was happened in left thigh, right thigh, left foot and right foot.

xxiii) Based on ergonomic evaluation and subjects' feedback, ODR, OSR, OER and BPDS a suitable ergonomically designed coconut climbing device was modified. Seating unit of Kerasuraksha coconut climbing device and pedal unit of KAU coconut palm climber were ergonomically comfortable for the climbing operator.

xxiv) The modified model was ergonomically evaluated and compared it with selected five models. It was found that it could reduce fatigue and improve efficiency. Also weight comparatively less, that makes operation ease.

xxv) Mean energy cost of new model was 23.02 kJ min^{-1} for male operators. It ranges from minimum value of 15.78 kJ min^{-1} and maximum value of 27.30 kJ min^{-1}. Energy cost decreased by the rate of 10.8 per cent when compared to Sit and climb type (TNAU model) and with KAU coconut palm climber it is comparable.

xxvi) For female subjects, energy cost of new model was decreased by 7.8 per cent with Kerasuraksha coconut climbing device and 6.2 per cent with Sit and climb type (TNAU model) and it is comparable with KAU coconut palm climber.

xxvii) Mean VO_2, oxygen consumption in terms of VO_2max and work pulse of new model was 1.10, 58.16 per cent and 69.70 beats min^{-1} for male and for female it was 1.22, 73.45 per cent and 81.10 beats min^{-1} respectively. These values are comparatively less than value of other five models.

xxviii) New model was graded as Heavy for male subjects and for female model it was Very heavy. It was seen that similar trend was for other selected five coconut climbing devices.

xxix) The time required for climbing new model was 65.01 sec for male subjects which was less than other five selected coconut climbing devices and same for female also. Female subjects were also taken less time of 75.51 sec to climb with new model when compared with other models.

xxx) The setting time of the new model was 65 sec while for KAU coconut palm climber it was 150 sec. Time was reduced by 56.67 per cent compare to KAU coconut palm climber.

xxxi) Male and female subjects had scaled as more than light discomfort with value of 3.4 and 3.8 respectively for ODR. OSR rated as “More than secure and meager fear” for both female and male with a value of 2.8 and rated easy for OER. And scored BPDS as 25.2 and 27.9 for male and female respectively.

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Appendices

APPENDIX I

Heart rate of male and female subjects while operating selected five models

Sl. No.	Name	Resting heart rate (Beats min^{-1})	Equipment	Heart rate (beats min^{-1})	Time (sec)
1	Minilal	61	TNAU model	133.5	104.9
				130	96.02
				129.5	94.5
			Chemberi model	124	58
				128.5	57.5
				123	59.41
			KAU coconut climber	126	86.3
				127	81
				128.5	84.2
			Kera Sureksha	130.5	97.7
				128.5	88.6
				133	88.2
			CPCRI model	123	64.6
				122.5	67.5
				128	64.3
2	Mardona	74	TNAU model	135.5	75.7
				141.5	47.2
				143.5	79.1
			Chemberi model	139	51.3
				143.5	62.2
				143.5	62.5
			KAU coconut climber	142	65.8
				138.5	57.4

				137.5	68.5
			Kera Sureksha	141.5	66.6
				140.5	65.6
				141.5	71.5
			CPCRI model	153.5	74.4
				144.5	74.6
3	Rajeesh	61	TNAU model	156.5	64.6
				131	71.1
				150.5	60.7
			Chemberi model	145	69.2
				146.5	70.3
				144	68.3
			KAU coconut climber	140	69.4
				137.5	71.4
				136	68.2
			Kera Sureksha	148.5	66.2
				162	63.2
				158	68.7
			CPCRI model	141.5	75
				141.5	73.4
				144.5	76.6
4	Rahul	72	TNAU model	138	72.7
				148	93.3
				137.5	88.7
			Chemberi model	132	62.4
				136.5	64.8
				137	64.9
			KAU coconut climber	135.5	58.2
				136.5	60.5

				133.5	58.1
			Kera Sureksha	136.5	68.6
				135.5	66.3
				133	66.2
			CPCRI model	132	74.5
				136	75.8
				136	75.4
5	Unni krishnan	51	TNAU model	146.5	100.32
				148	113.4
				146.5	112.5
			Chemberi model	137	73
				142	76.6
				135.5	83
			KAU coconut climber	134	86.3
				136.5	86.4
				122	85.3
			Kera Sureksha	139.5	101.5
				138.5	95.6
				138.5	80.3
			CPCRI model	136.5	85.1
				137.5	87.8
				138	87.4
6	Sunitha	81	TNAU model	166	110.6
				158.5	120.02
				163.5	119.1
			Chemberi model	175	116.1
				174.5	115.1
				173.5	116.5
			KAU coconut climber	161.5	104.3

				163	111.3
				162.5	103.3
			Kera Sureksha	165.5	103.2
				171	116.7
				168	111.4
			CPCRI model	164	118.1
				165	115.4
				162	118.11
7	Manju	72	TNAU model	164.5	117.15
				170.5	105.72
				173	110.15
			Chemberi model	169.5	70.3
				172	78.6
				174.5	74.7
			KAU coconut climber	167	71.3
				164	66.3
				165	65.6
			Kera Sureksha	171.5	107.23
				170	108.83
				173	101
			CPCRI model	166.5	77.3
				170.5	78.8
				169	84.6
8	Sujitha	63	TNAU model	142.5	107.1
				141	108.9
				142.5	111.6
			Chemberi model	137.5	69.1
				140.5	80.9
				144	72.3

			KAU coconut climber	134	86.1
				135.5	84.1
				136	88
			Kera Sureksha	143	117.1
				137.5	95.3
				140.5	96.3
			CPCRI model	142	65.3
				142.5	70.4
				145	67.7
9	Siji	66	TNAU model	159.5	118.1
				164.5	121.7
				162	121.51
			Chemberi model	156.5	70.3
				156.5	71.8
				155	67.5
			KAU coconut climber	150	72.2
				154.5	68.9
				153.5	71.9
			Kera Sureksha	160	111.2
				159.5	110.72
				159	105
			CPCRI model	151	74.5
				153	77.2
				155	79.12
10	Bindu	65	TNAU model	145.5	92.9
				149.5	92.6
				146.5	88.3
			Chemberi model	134.5	61.1
				140	66

				136.5	60
			KAU coconut climber	134.5	76.9
				135.5	69.9
				136	66
			Kera Sureksha	148.5	87.5
				151	89.4
				152	84.7
			CPCRI model	142	59.6
				141.5	60.1
				141.5	60.7

APPENDIX II

a. ODR, OER and OSR of male values for different models of coconut tree climbing devices

	TNAU			**Chemberi**			**KAU**			**Kerasuraksha**			**CPCRI**		
Subject	ODR	OSR	OER	ODR	OSR	OER	ODR	OSR	OER	ODR	OSR	OER	ODR	OSR	OER
Subject 1	5	4	6	3	4	2	3	2	2	5	4	4	3	4	2
Subject 2	3	2	2	0	4	0	3	0	0	3	2	2	3	2	2
Subject 3	5	4	4	3	4	2	3	2	2	3	2	4	3	2	4
Subject 4	3	2	6	0	4	4	3	2	2	5	2	4	3	2	4
Subject 5	5	2	4	3	4	2	3	2	2	5	4	4	5	4	4
	4.2	2.8	4.4	1.8	4	2	3	1.6	1.6	4.2	2.8	3.6	3.4	2.8	3.2

b. ODR, OER and OSR of female values for different models of coconut tree climbing devices

	TNAU			Chemberi			KAU			Kerasuraksha			CPCRI		
Subject	ODR	OSR	OER	ODR	OSR	OER	ODR	OSR	OER	ODR	OSR	OER	ODR	OSR	OER
Subject 1	7	6	8	3	4	2	3	2	2	3	4	4	5	2	4
Subject 2	7	6	8	5	6	4	3	4	4	5	4	4	5	2	6
Subject 3	5	4	6	5	6	4	3	2	2	3	2	4	5	2	4
Subject 4	5	6	8	5	4	2	3	4	2	3	2	4	3	2	4
Subject 5	5	4	6	3	6	2	3	2	2	5	4	4	5	2	4
	5.8	5.2	7.2	4.2	5.2	2.8	3	2.8	2.4	3.8	3.2	4	4.6	2	4.4

APPENDIX III

a. BPDS of male subjects for different model

	TNAU					Chemberi					KAU				
Subject	1	2	3	4	Mean	1	2	3	4	Mean	1	2	3	4	Mean
Subject 1	26,27	14,15	20,21	18,19		18,19	14,15	12,13	22,23		20,21	18,19	12,13	14,15	
	12	9	6	3	30	12	9	6	3	30	12	9	6	3	30
Subject 2	26,27,19	17,18	14,15	20,21,16		18,19	14,15	22,23	12,13		20,21	18,19	17	16	
	18	9	6	4.5	37.5	12	9	6	3	30	12	9	3	1.5	25.5
Subject 3	26,27	20,21	17,18	19		18,19,17	12,13	16	14,15		18,19	17	17		
	12	9	6	1.5	28.5	18	9	3	3	33	12	4.5	3	0	19.5
Subject 4	26,27	20,21	14,15	17,18		18,19	16	17	22,23		18,19	20,21	17	16	
	12	9	6	3	30	12	4.5	3	3	22.5	12	9	3	1.5	25.5
Subject 5	26,27,18	17,19	14,15	16		18,19	17	14,15	22,23		18,19	20,21	12,13	14,15	

	18	**9**	**6**	**1.5**	**34.5**	**12**	**4.5**	**6**	**3**	**25.5**	**12**	**9**	**6**	**3**	**30**
				mean	**32.1**				**mean**	**28.2**				**mea n**	**26.1**

	Kerasuraksha					**CPCRI**				
Subject	**1**	**2**	**3**	**4**	**Mean**	**1**	**2**	**3**	**4**	**Mean**
Subject 1	**26,27**	**20,21**	**12,13**	**14,15**		**4,5**	**18,19**	**12,13**	**22,23**	
	12	**9**	**6**	**3**	**30**	**12**	**9**	**6**	**3**	**30**
Subject 2	**26,27**	**20,21**	**12,13**	**13**		**4,5**	**18,19**	**12,13**	**22,23**	
	12	**9**	**6**	**1.5**	**28.5**	**12**	**9**	**6**	**3**	**30**
Subject 3	**26,27**	**18**	**12,13**	**13**		**4,5**	**18**	**19**	**17**	
	12	**4.5**	**6**	**1.5**	**24**	**12**	**4.5**	**3**	**1.5**	**21**
Subject 4	**26,27**	**20,21**	**12,13**	**17**		**4,5**	**22,23**	**19**	**17**	
	12	**9**	**3**	**1.5**	**25.5**	**12**	**9**	**3**	**1.5**	**25.5**
Subject 5	**26,27**	**20,21**	**12,13**	**16**		**4,5**	**18,19**	**,12,13**	**17**	
	12	**9**	**6**	**1.5**	**28.5**	**12**	**9**	**6**	**1.5**	**28.5**
				mean	**27.3**				**mean**	**27**

b. BPDS of male subjects for different model

	TNAU					**Chemberi**					**KAU**				
Subject	**1**	**2**	**3**	**4**	**Mean**	**1**	**2**	**3**	**4**	**Mean**	**1**	**2**	**3**	**4**	**Mean**
	26,27,19	**20,21**	**14,15**	**12,13**		**18,19**	**17**	**22,23**	**12,13**		**20,21**	**18,19**	**17**	**14,15**	
Subject 1	**18**	**9**	**3**	**3**	**33**	**12**	**4.5**	**6**	**3**	**25.5**	**12**	**9**	**3**	**3**	**27**
	26,27,19	**18,17**	**20,21**	**14,15**		**18,19**	**12,13**	**14,15**	**17**		**20,21**	**18,19**	**17**	**14,15**	
Subject 2	**18**	**9**	**6**	**3**	**36**	**12**	**9**	**6**	**1.5**	**28.5**	**12**	**9**	**3**	**3**	**27**
	26,27,19	**20,21**	**17,18**	**14,15**		**18,19**	**12,13**	**14,15**	**22,23**		**20,21**	**17**	**12,13**	**18,19**	
Subject 3	**18**	**9**	**6**	**6**	**39**	**12**	**9**	**6**	**3**	**30**	**12**	**4.5**	**6**	**3**	**25.5**

	26,27	18,19	14,15	20,21		18,19	14,15,	22,23	17		18	20,21	14,15	17	
Subject 4	12	13.5	9	3	37.5	12	9	6	1.5	28.5	6	9	6	1.5	22.5
	26,27	18,19	20,21	14,15		18,19	14,15	12,13	22,23		20,21	18,19	12,13	14,15	
Subject 5	12	9	9	3	33	12	9	6	3	30	12	9	6	3	30
					35.7					28.5					26.4

	Kerasuraksha					CPCRI				
Subject	1	2	3	4	Mean	1	2	3	4	Mean
Subject 1	26,27	19	20,21	16		4,5	18	12,13	14,15	
	12	4.5	3	1.5	21	12	4.5	6	3	25.5
Subject 2	26,27	20,21	18	12,13		4,5	18,19	22,23	14,15	
	12	9	3	3	27	12	9	6	3	30
Subject 3	26,27	19	20,21	12,13		4,5	18,19	12,13,	14,15,22,23	
	12	4.5	6	3	25.5	12	9	6	6	33
Subject 4	26,27	18	20,21	12,13		4,5	18	12,13	19	
	12	4.5	6	3	25.5	12	4.5	6	1.5	24
Subject 5	26,27	20,21	12,13	17		4,5	18,19	22,23	12,13,14,15	
	12	9	6	1.5	28.5	12	9	6	6	33
					25.5					29.1

APPENDIX IV

a. ANOVA of male subjects for heart rate

		Sum of Squares	D f	Mean Square	F	Sig.
Subject 1	Between Groups	109.9	4	27.475	4.697	*
	Within Groups	58.5	10	5.85		
	Total	168.4	14			
Subject 2	Between Groups	108.433	4	27.108	2.177	NS
	Within Groups	124.5	10	12.45		
	Total	232.933	14			
Subject 3	Between Groups	545.733	4	136.433	2.909	NS
	Within Groups	469	10	46.9		
	Total	1014.733	14			
Subject 4	Between Groups	91.767	4	22.942	2.141	NS
	Within Groups	107.167	10	10.717		
	Total	198.933	14			
Subject 5	Between Groups	397.767	4	99.442	6.78	*
	Within Groups	146.667	10	14.667		
	Total	544.433	14			

b. ANOVA of female subjects for heart rate

		Sum of Squares	df	Mean Square	F	Sig.
Subject 1	Between Groups	311.6	4	77.9	15.175	*
	Within Groups	51.333	10	5.133		
	Total	362.933	14			
Subject 2	Between Groups	84.733	4	21.183	3.115	*
	Within Groups	68	10	6.8		
	Total	152.733	14			
Subject 3	Between Groups	112.767	4	28.192	6.242	*
	Within Groups	45.167	10	4.517		
	Total	157.933	14			
Subject 4	Between Groups	199.067	4	49.767	14.782	*
	Within Groups	33.667	10	3.367		
	Total	232.733	14			
Subject 5	Between Groups	503.833	4	125.958	39.362	*
	Within Groups	32	10	3.2		
	Total	535.833	14			

c. ANOVA of male subjects for energy cost

		Sum of Squares	df	Mean Square	F	Sig.
Subject 1	Between Groups	19.006	4	4.751	4.687	*
	Within Groups	10.137	10	1.014		
	Total	29.142	14			
Subject2	Between Groups	7.414	4	1.853	2.181	NS
	Within Groups	8.497	10	0.85		
	Total	15.911	14			
Subject 3	Between Groups	60.942	4	15.236	2.91	NS
	Within Groups	52.361	10	5.236		
	Total	113.303	14			
Subject 4	Between Groups	9.987	4	2.497	2.14	NS
	Within Groups	11.669	10	1.167		
	Total	21.657	14			
Subject 5	Between Groups	68.654	4	17.163	6.77	*
	Within Groups	25.354	10	2.535		
	Total	94.008	14			

d. ANOVA of female subjects for energy cost

		Sum of Squares	df	Mean Square	F	Sig.
Subject 1	Between Groups	51.134	4	12.783	15.197	*
	Within Groups	8.412	10	.841		
	Total	59.546	14			
Subject2	Between Groups	3.319	4	0.83	3.115	*
	Within Groups	2.664	10	0.266		
	Total	5.983	14			
Subject 3	Between Groups	9.613	4	2.403	6.231	*
	Within Groups	3.857	10	0.386		
	Total	13.47	14			
Subject 4	Between Groups	15.818	4	3.955	14.757	*
	Within Groups	2.68	10	0.268		
	Total	18.498	14			
Subject 5	Between Groups	36.51	4	9.128	39.4	*
	Within Groups	2.317	10	0.232		
	Total	38.827	14			

APPENDIX V

a. BPDS of male subjects for new model

Subjects	I	II	III	IV	Mean
Subject 1	17,18	19	14,15	16	
	12	4.5	6	1.5	24
Subject 2	17,18	16	14,15	_	
	12	4.5	6	0	22.5
Subject 3	18,19	14,15	17	20,21	
	12	9	3	3	27
Subject 4	20,21	18	14,15,	12,13	
	12	4.5	6	3	25.5
Subject 5	17,18	14,15	20,21	_	
	12	9	6	0	27
				Mean	25.2

b. BPDS of female subjects for new model

Subjects	I	II	III	IV	Mean
Subject 1	17,18	12,13	14,15	19	
	12	9	6	1.5	28.5
Subject 2	18,19	16	14,15	12,13	
	12	4.5	6	3	25.5
Subject 3	18,19	12,13	20,21	17	
	12	9	3	1.5	25.5
Subject 4	20,21,19	18	14,15,	12,13	
	18	4.5	6	3	31.5
Subject 5	18,19	14,15	12,13	17	
	12	9	6	1.5	28.5
				Mean	27.9

APPENDIX VI

a. ODR, OER and OSR of male values for new model

Subjects	ODR	OSR	OER
Subject 1	3	2	2
Subject 2	3	2	2
Subject 3	3	4	2
Subject 4	5	4	2
Subject 5	3	2	2
	3.4	2.8	2

b. ODR, OER and OSR of female values for new model

Subjects	ODR	OSR	OER
Subject 1	3	2	2
Subject 2	3	4	4
Subject 3	5	2	2
Subject 4	3	4	2
Subject 5	5	2	2
	3.8	2.8	2.4

ABSTRACT

At present there are different models of coconut climbing devices available in the market. Most of the climbing devices safety and efficiency aspects are not being studied and needs to be comparatively evaluated and modified. In this study five coconut climbing devices were selected, those are Sit and climb type (TNAU model), Standing type (Chemberi model), KAU coconut palm climber (developed at KCAET), Kerasureksha (Model developed at ARS, Mannuthy) and CPCRI model coconut climbing device. Pertinent anthropometric dimensions of human subjects with reference to the dimensions and positions of the functional components of coconut climbing devices was identified and 35 different body dimensions useful for the design or redesign of coconut climbing devices were recorded by following standard anthropometric procedure. Ten subjects (five each for men and women) were selected, conforming to statistical requirements of anthropometric dimensions. The selected ten subjects were screened for normal health through medical and bio-clinical investigations which includes Electro Cardio Graph (ECG), blood pressure and bio-clinical analysis. Selected ten subjects were calibrated in the laboratory by indirect assessment of oxygen uptake. The relationship between the heart rate and oxygen consumption of the subjects was found to be linear for all the subjects. Then energy cost of operation of the selected coconut climbing devices were computed by multiplying the oxygen consumed by the subject during the trial period with the calorific value of oxygen as 20.88 kJ lit^{-1}. Energy cost is comparatively less for KAU coconut palm climber with other models. Mean energy cost of male subjects during the operation of KAU coconut palm climber is 23.16 kJ min^{-1} and female shows 25.73 kJ min^{-1}. Variation of heart rate and energy cost of both male and female for selected five models were statistically analyzed. Female subjects are significantly differed in both heart rate and energy cost on different coconut climbing devices and all the female subjects showed minimum heart rate while operating KAU coconut palm climbing device. But male subjects are shown any significant difference for both heart rate and energy cost. But they shows comparatively less

heart rate for KAU coconut palm climbing device. The oxygen uptake in terms of VO_2 max was minimum for KAU coconut palm climber (58.53 per cent) while it was 65.22 per cent for Sit and climb type (TNAU model) for male operators. Similarly for female subjects, minimum for KAU coconut palm climber (74.30 per cent). Sit and climb type (TNAU model) is difficult in operation compared with other devices. Major discomfort was happened in left thigh, right thigh, left foot and right foot. Based on these results it was found that KAU coconut palm climber and Kerasuraksha coconut climbing device were identified as more suitable for climbers than other climbing devices. Seating unit of Kerasuraksha coconut climbing device and pedal unit of KAU coconut palm climber were ergonomically comfortable for the climbing operator and developed a new model by incorporating the constructional behavior of both KAU coconut palm climber and Kerasuraksha coconut climbing device. Energy expenditure of new model for male is decreased by the rate of 10.8per cent when compared to Sit and climb type (TNAU model and with KAU coconut palm climber it is comparable. In the case of female subjects, Energy cost of new model was decreased by 7.8 per cent with Kerasuraksha coconut climbing device and 6.2 per cent with Sit and climb type (TNAU model) and it is comparable with KAU coconut palm climber. Mean VO_2, VO_2 max and work pulse of new model is 1.10, 58.16 per cent and 69.70 beats min^{-1} for male and for female it is 1.22, 73.45 per cent and 81.10 beats min^{-1} respectively. These values are comparatively less than value of other five models. The time required for climbing new model was 65.01 sec for male subjects which are less than other five selected coconut climbing devices and same trend for female also. The setting time of the new model was 65 sec while for KAU coconut palm climber it was 150 sec. Time was reduced by 56.67 per cent compare to KAU coconut palm climber.