DESIGN AND DEVELOPMENT OF MANUAL NUTMEG (*Myristica fragrans* Houtt.) HARVESTING SYSTEM

A Thesis submitted to the

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI – 415 712.
Maharashtra State (India)

In the partial fulfillment of the requirements for the degree of

MASTER OF TECHNOLOG
(AGRICULTURAL ENGINEERING)

in

FARM MACHINERY AND POWER

By
Yamagar Somnath Gangaram
B. Tech. (Agril. Engg.)
(Reg. No. ENDPM-2016/0118)

DEPARTMENT OF FARM MACHINERY AND POWER
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI – 415 712. DIST. – RATNAGIRI. M.S. (INDIA)

JULY 2018

DESIGN AND DEVELOPMENT OF MANUAL NUTMEG

(*Myristica fragrans* Houtt.) HARVESTING SYSTEM

A Thesis submitted to the

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH

DAPOLI – 415 712.

Maharashtra State (India)

In the partial fulfillment of the requirements for the degree

of

MASTER OF TECHNOLOGY

(AGRICULTURAL ENGINEERING)

in

FARM MACHINERY AND POWER

Submitted by

Yamagar Somnath Gangaram

(Reg. No. ENDPM/2016/0118)

Approved by

(Dr. K. G. Dhande)
Associate Professor, Dept. of FMP
(Chairman and Research Guide)

(Dr. V. V. Aware)
Professor (CAS), Dept. of FMP
(Committee Member)

(Dr. S. V. Pathak)
Associate Professor, Dept. of FMP
(Committee Member)

(Dr. R. G. Khandekar)
Associate Professor, Dept. of Horticulture
(Committee Member)

DEPARTMENT OF FARM MACHINERY AND POWER
COLLEGE OFAGRICULTURAL ENGINEERING ANDTECHNOLOGY DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI – 415 712. DIST- RATNAGIRI. M.S. (INDIA)

JULY 2018

CANDIDATE'S DECLARATION

I hereby declare that the experimental work and its interpretation of the thesis entitled **"Design and Development of Manual Nutmeg (*Myristica fragrans* Houtt.) Harvesting System"** or part of thereof has not been submitted for any other degree or diploma of any University, nor the data has been derived from any thesis/publication of any University or scientific organization. The sources of materials used and all assistance received during the course of investigation have been duly acknowledged.

(Yamagar Somnath Gangaram)
(Reg. No. ENDPM/2016/0118)

Place: **Dapoli**
Date: 07/08/2018
ENDPM/2016/0118)

Dr. K. G. Dhande
M. Tech (FMP), Ph. D (FMP)
Associate Professor and Research Guide,
Department of Farm Machinery and Power,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the research project report entitled **"Design and Development of Manual Nutmeg (*Myristica fragrans* Houtt.) Harvesting System"** submitted to the Faculty of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in the partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in **FARM MACHINERY AND POWER** embodies the record of a piece of bonafide research work carried out by **Mr. Yamagar Somnath Gangaram (Regd. No. ENDPM-2016/0118)** under my guidance and supervision. No part of the research project report has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this project work and sources of the literature have been duly acknowledged.

Place: Dapoli
Date: 07/08/2018

(K. G. Dhande)
Chairman,
Advisory Committee and Research Guide

Dr. P. U. Shahare
B. Tech. (Agril. Engg.), M.Tech. (FMP), Ph. D.
Professor and Head,
Department of Farm Machinery and Power,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli - 415712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the research project report entitled **"Design and Development of Manual Nutmeg (*Myristica fragrans* Houtt.) Harvesting System"** submitted to the Faculty of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli Dist. Ratnagiri (Maharashtra State) in the partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in **FARM MACHINERY AND POWER** embodies the record of a piece of bonafide research work carried out by **Mr. Yamagar Somnath Ganagaram (Regd. No. ENDPM-2016/0118)** under the guidance and supervision of **Dr. K. G. Dhande**, Associate Professor, Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Dapoli. No part of the project report has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this project work and sources of the literature have been duly acknowledged.

Place: Dapoli
Date:
Head

(P. U. Shahare)
Professor and Head
Department of Farm Machinery and Power

Dr. Y. P. Khandetod
B. Tech. (Agril. Engg.), M. Tech. (IIT), Ph. D.
Dean,
Faculty of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the project report entitled **"Design and Development of Manual Nutmeg (*Myristica fragrans* Houtt.) Harvesting System"** submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in the partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)** in **FARM MACHINERY AND POWER**, embodies the record of a piece of bonafied research work carried out by **Mr. Yamagar Somnath Ganagaram (Regd. No. ENDPM-2016/0118)** under the guidance and supervision of **Dr. K. G. Dhande**, Associate Professor, Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Dapoli. No part of the project report has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this project work and sources of the literature have been duly acknowledged.

Place: Dapoli
Date:

(Y. P. Khandetod)
Dean,
Faculty of Agricultural Engineering

ACKNOWLEDGEMENT

The globe turns round the time passes by passing of time every beautiful thing to come to an end. As the end of my Master education is in sight, a sudden realization makes me ponder over the last two years. This is indeed my last and only opportunity to express sincere gratitude towards all who wished me success and help me of my studies.

At the outside, words are not enough to describe the deep affection, respect and hearted gratitude for my Chairman and Honorable Research Guide **Dr. K. G. Dhande**, Associate Professor, Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Dapoli, whose unquestioned mastery on the subject, profound interest in the research, inspiring guidance, constructive criticism, ever willing help, kind and soft touch of love and affection throughout the course of my post graduate studies and experience given while, this study and preparation of this thesis will be a treasure to me forever.

I am especially indebted to **Dr. P. U. Shahare**, Professor and Head, Department of Farm Machinery and Power, for his valuable suggestion and guidance from very inception of the research work. I take this privilege as a pleasant duty to express my deep sense of gratitude to the members of Advisory committee, **Dr. V. V. Aware**, Professor, Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Dapoli, **Dr. S. V. Pathak**, Associate Professor, Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Dapoli and **Dr. R. G. Khandekar**, Associate Professor, Department of Horticulture, College of Agriculture, Dapoli. Their scholarly guidance and active support, constant encouragement and sincere help right from the beginning of this work.

I express sincere gratitude to **Dr. Y. P. Khandetod**, Associate Dean, College of Agricultural Engineering and Technology., Dapoli for providing all the needed facilities, which were essential for successfully completion of the project work.

Grateful thanks are extended to **Er. N. S. Shirsat**, Assistant Professor, Department of Farm Machinery and Power, for his timely valuable guidance in the research work. I express my heartiest thanks to **Mrs. R. N. Palte**, Senior Research Assistant, Department of Farm Machinery and Power, who had been a source of immense help to me during the course of this investigation.I am thankful to **Dr. Sachin Wandkar**, Assistant Professor, Department of Farm Machinery and Power, for his constant support and coordination during calibration of subject.

No words can adequately express our indebtedness to workshop members, **Mr. Gimhavanekar N. S**., **Mr. Mahadik S. V**., **Mr. Jadhav S. S**., **Mr. Kadam S. R**., **Mr. Parab M. K**., **Mr. Mane M. S**, who have been a source of immense help to me during the course of this project.I am thankful to **Mr. Tambe S. J**., Lab Assistant and **Shri. Chogale H. G**. Foreman Supervisor for their advice and help.

I would like to offer my special thanks to my colleagues **Siddhi Sanjay Borkar** and **Sayali Vikas Kamerkar** for their excellent co-operation during study.

I am also indebted to **Shri. L. V. Jivane** and **all security guards**, **Kisan Bhavan**, **ST Canteen, University library, Dapoli staff** for their kind cooperation's help during my studies at Dapoli.

One personal note, I could not found a word in my diction to translate my heartlet gratitude and respect to my father **Shri. Gangaram Damodhar Yamagar**, Mother **Sou. Sindhu Ganagaram Yamagar**, Sister's **Miss. Sangita Arjun Karhe**, **Miss. Sunnada Ajinath Kale**, **Miss. Megha Gosavi** and **Miss. Suvarnsandhya Dadas** and my father's friend **Shri. Rohidas Harishchandra Dadas** and **Shri. Arjun Santram Aghav** for their boundless love affection, words of encouragement, selfless sacrifice and unshakable confidence with me that had a direct effect in completing this work and accomplishes my studies successfully.

I express my sincere thanks to those who directly and indirectly extended help during the research work.

Place: **Dapoli**

Dated:

(Yamagar Somnath Gangaram)

(Reg. No. ENDPM/2016/0118)

TABLE OFCONTENTS

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviations	**Meanings**
Agril.	Agricultural
Agril. Engg.	Agricultural Engineering

AICRP	All India Co-ordinated Research Project
ASAE	American Society of Agriculture Engineering
AWL	Acceptable Work Load
BPDS	Body Parts Discomfort Score
bpm	beats per minute
CAET	College of Agricultural Engineering and Technology
CG	Centre of garvity
cm	Centimeter
CO_2	Carbon Dioxide
CV	Coefficient of variation
DBAU	Department of Botany Andhra University
Deptt.	Department
dia.	Diameter
Dr. BSKKV	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
EE	Energy Expenditure
EER	Energy Expenditure Rate
Engg.	Engineering
Er.	Engineer
ESA	Ergonomics and Safety in Agriculture
et al.	And others
etc.	Etcetera
FAO	Food Agriculture Organization
FDF	Fruit Detachment Force
Fig.	Figure
ft.	feet
g	Gram
ha	hectare
hort.	horticulture
hp	horse power
h	hour
HR max	Maximum Heart Rate
Hz	Hertz
i.e.	That is
IARI	Indian Agricultural Research Institute
IIHR	Indian Institute of Horticulture

J.	Journal
Kcal	Kilo calorie
Kg	Kilogram
Kg/h	Kilogram per hour
KJ	Kilo joule
KJ min-1	Kilo Jules per minute
KW	Kilo Watt
L	Liter
L	Length
LCP	Limit of Continuous Performance
M	Mass
M	Meter
M.S.	Maharashtra State
M. Tech	Master of Technology
MVC	Maximal Voluntary Condition
m/s	meter per second
min.	minute
Mm	Millimeter
MS	Mild Steel
N	Newton
N/g	Newton per gram
N-m	Newton meter
Nos.	Numbers
O_2	Oxygen
OCR	Oxygen Consumption Rate
ODR	Overall Discomfort Rating
OWAS	Ovako Working Posture Analysis System
Pp.	page to page
PTO	Power Take Off
RHR	Resting Heart Rate
rpm	revolutions per minute
RRTC	Regional Training and Testing Centre
Rs	Rupees
Rs/h.	Rupees per hour
S.D	Standard Deviation

Sci.	Science
sec.	second
TMHE	Tractor Mounted Hydraulic Elevator
VCO_2	Volume of Carbon Dioxide Emission
VO_2 max	Maximum Volume of Oxygen

LIST OF SYMBOLS

Symbols	Description
%	Per cent
=	Equal to
+	Plus

-	Minus
×	Multiplication
/	Division
±	Plus or minus
Σ	Summation
<	Less than
>	Greater than
0	Degree
σ	Sigma
@	About
θ	Theta
0^{C}	Degree Celsius
Δ	Delta

ABSTRACT

DESIGN AND DEVELOPMENT OF MANUAL NUTMEG (*Myristica fragrans* Houtt.)HARVESTING SYSTEM

By

Mr. Yamagar Somnath Gangaram

College of Agricultural Engineering and Technology,

Dr. BalasahebS awant Konkan Krishi Vidyapeeth, Dapoli-415 712,
Dist. Ratnagiri, (Maharashtra)
2018

Research Guide: Dr. K. G. Dhande

Department: Farm Machinery and Power

Nutmeg (*Myristica fragrans* Houtt.) is an important tree spice which produces two different spices namely nutmeg and mace. The nutmeg fruits are harvested on time and at the proper stage of maturity in order to maintain their nutrients level as well as attaining desirable quality. The Konkan region is well regarded as fruit belt of Maharashtra. Presently, the method adopted for harvesting nutmeg in Konkan region is by manual means i.e. by hand picking, by shaking the tree branches or by using bamboo stick having a curved hook. It was therefore, necessary to develop harvesting system with simple design, easy for operation, low cost but with higher working efficiency. In view of this thesis, the present investigation entitled, "Design and Development of Manual Nutmeg (*Myristica fragrans* Houtt.) Harvesting System" was carried out at Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, DBSKKV, Dapoli.

To overcome the problem and limitations of the traditional harvesting methods, a manually operated Nutmeg harvesting system was designed, developed and fabricated based on requirement and anthropometric parameters of workers. The developed nutmeg harvesting system consists of fruit harvester, telescopic pole, harvesting platform and fruit collecting basket. The performance of developed Nutmeg harvesting system was evaluated in field and it's harvesting capacity and damage fruit per cent was found to be 8.15 kg/h and 1.33 % respectively and only one person was required for harvesting operation. The cost of harvesting nutmeg with newly developed manual Nutmeg harvesting system, hook method and beating of fruits by bamboo stick was found to be Rs/kg 5.93, 17.16 and 43.10 respectively. The newly developed Nutmeg harvesting system proved to be superior, efficient and economical over traditional harvesting method.

CHAPTER I

INTRODUCTION

India is the second largest producer of fruits in the world. The area under cultivation 6.58 million hectare and production 77.52 million tonnes in the year 2011-

2012. Maharashtra state rank second in the production of fruits in the India. The Konkan region is well regarded as fruit belt of Maharashtra. Konkan coastal region is flanked by Arabian Sea on the west and Sahyadri ranges on the east comprises of Ratnagiri, Sindhudurg, Raigad and Thane districts. The region is characterized with hilly terrain and warm and humid climate. The coastal plains are adorned with coconut and areca nut, orchards while hilly slopes and plateau are covered with Mango, Cashew, Jackfruit, Kokum, Coconut, Aonla, Sapota, Jamun and Nutmeg plantations. The total area under fruit crops in the state is 12.50 lakh hectares and Konkan is 3 lakh hector during last decade. However, still about 4.0 lakh hectare cultivable warkas land is available for plantation of fruit crops.

Nutmeg (*Myristica fragrans* Houtt.) is an important tree spice which produces two different spices namely nutmeg and mace. It belongs to the family *Myristicaceae* which is a small group comprising 16 genera and about 380 spices. It is mainly distributed to the low land tropical forests of the world. The major nutmeg growing regions are Guatemala and Indonesia. In India, it has occupied an area of about 19,670 ha with an annual production of 18,070 MT. It is grown in Tamil Nadu, Kerala, Karnataka, Assam, Andhra Pradesh, Maharashtra and Goa. The production of nutmeg in the country is still insufficient to meet the demand of the nation and hence a substantial quantity of Nutmeg is imported causing a huge loss of valuable foreign exchange (Anonymous, 2016).

In Konkan region of Maharashtra, Nutmeg was introduced by Portuguese in some pockets. In late 70’s, the Konkan Krishi Vidhyapeeth., Dapoli initiated research work on this crop with main aim to test its performance as mixed crop in coconut plantation. It was observed that nutmeg is the best-mixed crop in coconut plantation in comparison with other tree spices. The planting of nutmeg under coconut has been found to increase the productivity of coconut plantation by about 84 per cent which ultimately has resulted in high levels of net profit from the Nutmeg and coconut combination. After harvest, the outer fleshy portion (pericarp) is removed and the mace is manually separated from the nut and then dried separately in the sun. The scarlet coloured mace gradually becomes yellowish brown and brittle when drying is completed. The fleshy pericarp can be used for making pickles, jams and jellies.

The female nutmeg tree starts fruiting from sixth year, till the peak period is reached after 20 years. The fruits are ready for harvest in about 9 months after flowering. The peak harvesting season is during June to August. The fruits are considered as ripened and ready for harvesting when the pericarp splits open. If the ripped fruits are left on tree then there are chances of birds getting attracted towards the mace and nutmeg fruit gets carried by bird and rodent. All the fruits on the tree do not mature at the same time and hence harvesting has to be carried as per ripening of fruit (Anandaraj *et al.* 2005).

Harvesting is an important operation in horticultural crop production and improper methods lead to huge loss to grower. Unscientific harvesting results in damage of crop by bruising which can be caused by compression, impact or vibration. During harvesting, factors like delicacy of crop, maturity criteria, time of harvesting, mode of packaging and transportation, economy of operations should be taken in consideration.

The nutmeg fruits are harvested on time and at the proper stage of maturity in order to maintain their nutrients level as well as attaining desirable quality. The proper handling, packaging, transportation and storage reduce the post harvest losses. Numerous biochemical processes continuously change the original composition of the fruits until it becomes unmarketable. Nutmeg fruits are very delicate and perishable in nature at the time of maturity, they fall down the ground and deterioration takes place. To increase the market value and shelf life of the fruits, it has to harvest at proper time. To avoid this problem the fruits are harvested using manual and mechanical harvesting methods. It may be practical to use no tools and pick by hand, especially if the branches of small height Nutmeg plants near to the ground. The best way of breaking the more resistant peduncles is to twist the fruit at the same time as pulling or jerking. When picking within the crown, a light-weight hook on a pole is useful for pulling the branches within reach.

In other hands Nutmeg fruits with relatively weak peduncles and shaking a branch will produce enough momentum in the fruit to break its peduncle. The most common tool for shaking is a simple hook or gaff on a pole with which to hold and shake the branch. Sometimes beating with a stick may suffice.

Mechanical harvesting devices employ direct contact methods like combing, cutting, pulling, snapping, twisting, stripping and compacting. Mechanical harvesters are developed for many crops including apples, strawberries, blueberries, cherries, and raspberries. In most cases, harvesting involves shaking of tree or cane by mechanical vibration and catching detached fruit underneath in a large blanket or net. They consist basically of an articulated arm, mounted on a vehicle, with a clamp at the end which is used to grip the trunk of the tree. The arm is made to vibrate, thus shaking the trunk and hence the crown. These machines are expensive and only suitable for a few species and for high value seed in easily accessible plantations.

Presently, the method adopted for harvesting nutmeg in Konkan region is by manual means i.e. by hand picking, by shaking the tree branches or by using bamboo stick having a curved hook at its top end to detach a fruit from its pedicle which are present at the top of the tree. Another method of harvesting is to hit the fruits by stick. These methods result in causing mechanical damage to the fruit and also make the fruit unfit for further processes as falling from height damages the fruit. Fruit harvesting solutions have been developed since then with the primary focus on improving working efficiency and reducing fruit damage during harvesting. While harvesting all kinds of fruit, often the picker has to reach above shoulder height or below knee height and twisting of the back occurs. Neck and shoulder discomfort can also be caused by the repetitive moments of the arms when picking fruit and placing it in the container (Anonymous 2017).

All these primitive methods result in loss of considerable human energy, time, money and deterioration of fruits caused by falling on the ground and inefficient, drudgerous. Due to more drudgery in harvesting of nutmeg fruits, most of growers have diverted their attention from this fruit crop. It was therefore, necessary to develop harvesting system with simple design, easy for operation, low cost but with higher working efficiency. Hence to overcome the above said problems and provide solutions to small scale spice farmers, by considering the technique in the view and the necessity of the nutmeg harvesting in Konkan region of Maharashtra the work was undertaken in the department of the Farm Machinery and Power, College of Agricultural Engineering and Technology, Dapoli with the research entitled "Design and Development of Manual Nutmeg (*Myristica fragrans* Houtt.) Harvesting System" is undertaken with following objectives.

Objectives

1. To develop manual Nutmeg harvesting system.
2. To evaluate the field performance of the developed manual Nutmeg harvesting system.
3. To compare the cost economics of developed manual Nutmeg harvesting system with traditional harvesting method.

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with research work done in past by various investigators related to the selected study. The information of published work on physical properties of matured fruits and harvester of various horticultural fruits crops along with different design aspects are discussed in this chapter. The various studies reviewed are presented under the following heads

1. Fruit harvesting methods
2. Design of fruit harvesters
3. Performance evaluation of the fruit harvesters

4. Ergonomic evaluation of fruit harvesters

2.1. Fruit harvesting methods

Harvesting of fruits should be done at optimum stage of maturity. During harvesting operation, a high standard of field hygiene should be maintained. It should be done carefully at proper time without damaging the fruits. A different kind of fruit requires different methods of harvesting. The methods of harvesting are classified as manual harvesting (traditional harvesting method) and mechanical harvesting (improved harvesting method) (Shinde *et al*., 2012).

2.1.1. Manual harvesting

Anonymous (1966) the experiment was conducted at RTTC Jorhat., Assam and worked on manually operated fruit harvesting device. They developed two device one device consisted of two main parts i.e. one is cutting of fruit by the sickle or blade and second one is collecting the fruit in a bag. This unit was found suitable for big fruits which were damaged if allow falling freely on the ground. Another device worked on the principle of mechanical shaking of tree. This unit was suitable for hard fruits, which consisted of two tongs, adjustable for different heights by means of extension bars. Crank arrangement operated manually and provided with flywheel to shake the tree at proper frequency was connected to the tongs and placed on time ground. The tonges were fixed with main branch of the tree and shaking was done to detach the fruits. A net arrangement to collect the falling fruits was proposed to save the fruits from damage.

Powar *et al.* (2003) studied the results of comparative trials of improved mango harvester with local harvester. Results indicated that the improved mango harvester harvested almost all the fruits with pedicel. The quantity harvested by improved harvester was almost doubled as 130 fruits per hour where as it was only 68 fruits per hour with local zela. The percentages of fruits harvested by local zela with pedicel were 45.83 and 60.29 per cent, respectively only at both the locations. While harvesting with local harvester about 10 fruits per hour were dropped due to shaking of branches whereas there were no fruit drop observed with improved harvester. Thus, the improved mango harvester was found to be far supervisor over local method of harvester.

2.1.2. Mechanical harvesting

Anonymous (1989-b) the experiment was conducted on comparatively studied methods of harvesting Raspuri and Totapuri Mango at Indian Institute of Horticultural Research (IIHR), Banglore. Hand plucking without stalk, Hand plucking with stalk, local zela (conventional harvester) and Dapoli harvester were selected for study.

During operation, a group of three persons were required, two persons for harvesting fruits form tree and one person to catch the fruits on an apron or emptying the harvester net to avoid falling of fruit. The data regarding harvesting capacity, Stalk length, and visible damage, shelf life of fruits and cost of harvesting by different methods were recorded. It was concluded that harvesting mango with Dapoli harvester showed more visible damage and less cost of harvesting as compared to local zela.

Futch and Roka (2005) reported the use of two types of mechanical harvesters in Florida for citrus harvesting. One of the harvesting systems was a canopy shake harvester and catch harvester. It shakes tree canopies, causing fruit to fall onto a catch frame. Then fruit is carried through a conveyor system to the goat-like trucks. It can harvest 200 to 400 trees per hour. The second type of the harvesting system is called a trunk shake harvester, which shakes tree canopies, causing fruit to fall on the ground. Then a fruit picking crew manually collects the fruit.

Chagnon *et al*. (2007) developed a branch shaker to harvest the fruit of seabuckthorn. They experimentally resulted that to harvest fruit from the “Indian summer” cultivator efficiently by shaking the branches had to use a frequency of 40 Hz, amplitude of 15 mm and vibration time of 10 seconds. Using these parameters 90 per cent of the fruits were harvested with little damage to the branch and little debris (leaves, buds, wood) being detached from the branches.

Kolhe (2009) designed and tested tractor mounted hydraulic elevator (TMHE) for a mechanical harvesting of mangoes and coconuts, biometric parameters of mango and coconut trees such as a maximum and minimum height, Stem girth, number and weight of fruits harvested and yield were considered for the development of the TMHE. Results indicated that the THME is suitable for fruit harvesting, tree pruning and tree spraying operations. The THME is also suitable for harvesting mangoes and coconut or chards up to 15 m and pruning of trees up to 10 m height. Furthermore, the THME was found to be suitable for operation on plain fields as well as hilly terrain having up to 20.5 % slopes.

Hamam *et al.* (2011-a) studied the two prototypes of rotary cone harvesting and harvesting electrical scissors heads were designed, fabricated and evaluated to reduce the required number of manual picker and maximize its productivity that reduce harvesting costs. The rotary harvesting head was evaluated under four types of rotary cone and four cone rotational speeds of 300, 450, 600, and 750 rpm for harvesting of Washingtonia and Valencia orange fruits compared with traditional harvesting method. While the electrical scissors harvesting head was evaluated using five different skill labors for harvesting of Washingtonia, Valencia, Mandarin and Lemon citrus fruits compared with traditional harvesting method.

2.2 Design of fruit harvester

Seamount and Opitz (1973) developed of picking ladders and associated picking techniques, picking platforms to assist groups of pickers, and picker positioning devices for orange fruit and examined the overall efficiency of an 'auto picker' and compared to the use of 'ladder and bag picking'. The result showed that the time required pick a box of fruit using ladder was 8.07 min/box and with the 'auto picker' was 6.46 min/box. Hence, the two main position machines increased the productivity and picking efficiency of each picker. However, there was no such increase in productivity with the use of picking platforms.

Siwalak *et a1*. (1989) developed a hand held single fruit harvesting device and a mango Stem picker. The single fruit harvester was circular in shape and equipped with a cutter bar, which was actuated by a hand grip bicycle brake cable. The handle bar was made of three length of 2.84 cm (1.125 inch) diameter aluminum pipe. The mango stem picker consists of a 13 cm diameter circular wire frame. A 10 wire teeth in the form of an inverted 'U' was provided around the edges of the frame. The Wire frame was also support a cloth pouch. The device was attached to a 2 to 4 m long bamboo pole with an unloading mechanism. The device weights 1.6 kg and the harvesting capacity of device was 5 to 6 king oranges or 5 to 6 mangoes at one time.

Abou El-Kheir (1993) designed and developed a small hand held harvester machine arm for harvesting lime fruit. An are shape cutting blade was used to control catching and cutting the fruit peduncle. Evaluation of the harvester performance indicated that, the percentage of picked fruits to the total number of fruits ranged from 90 % to 100 %.

Anonymous (1996) designed and developed an improved mango harvester similar to developed harvester at Indian Agricultural Research Institute (IARI), Delhi. The device was capable of cutting the stem of fruit of 3 to 4 mm diameter from a height of 15 feet. It could harvest Dashchari mango at rate of 38 kg/hr. The equipment consisted of cutting blade, flexible cable with hand lever, conduit pipe and collection basket. Two horizontal blade made of high carbon steel with serrations were mounted on a mechanism which was operated with the help of flexible cable and hand lever. One end of the cable was connected to the cutting mechanism and the other end to the hand lever. A conduit pipe of 3000 mm long and 20 mm outer diameter was used for mounting the cutting mechanism and hand lever.

Sapowadia *et al.* (2001) studied the design and development of a mango harvesting device. The traditional manual harvesting of mango is time and labour intensive. In order to overcome these difficulties, three models of improved mango harvesting devices impact type, shear type and impact cum shear type were developed. Their performance in comparison to the traditional devices was evaluated. The impact type model was the best among three models with improved harvesting capacity, cost efficiency and less damage to the fruits. In other hand, the shear type model could not work due to the fibrous nature of pedicle of the Kesar variety of mango. With the use of impact type model, harvesting capacity could be increased by 18 % and visible damage to the mango fruits was reduced by 50 %.

Abou EI-magd *et al.* (2002) designed, fabricated and tested an orange detacher prototype in picking Washingtonia oranges. Their results indicated that the minimum fruit detachment time was obtained at a friction coefficient of about 0.81 for Washingtonia variety. The cone rotating speed of 680 rpm gave the best results for the shortest remaining twig height of 0.88 mm and optimum cone angle of 52°. The developed picking method was found superior when compared to the manual traditional picking method since it accomplished about 87.9 % of fruits grade (1), low percentages of fruit, with twig 9 % and fruits without calyx 3 %.

Gupta *et a1.* (2004) developed a tractor mounted positioner to reduce losses sustained during harvesting of mango and to maintain fruit quality. During operation, it was observed that using the positioner for harvesting. Only the mature fruits with stalk of 10 to 20 mm length without sap burns and any other damage to the fruits could be harvested. White layer (bloom), which is desirable from quality point of view, was also maintained. They observed that the work output was slightly reduced but overall economics was in favors of use of the positioner for harvesting as compared to the traditional picker. They found that using a positioner in orchards can save about Rs. 1000 per tree in a good season.

Mohamad *et al.* (2006) developed a fruit picker with adjustable height for picking tree-top and high-to-reach fruits. It could pick high fruits of most common tree varieties and weighed about 5 kg. Limited field trials indicated that the picker satisfactorily controlled the height. The device was also multi-purpose; it could be used for other small scale operations including pruning and spraying by fitting the appropriate attachment.

Adetan *et al.* (2007) studied then improved pole and knife method of harvesting oil palms. The harvesting pole was designed to consist of three sections made from three lengths of aluminium pipes. By treating the pole as a cantilever, deflection analysis was carried out on various lengths and diameters of aluminium poles to determine the sizes to procure for the construction. The topmost section of the pole was made form a 40 mm diameter and it carried the knife. It was 3.5 m in length (including the length of the knife which was 0.35 m long) The middle and bottom sections were each made from 2.1 m lengths of 60 mm diameter and 52 mm. The top and middle sections when connected together, was 5.6 m long while the three sections together measured 7.7 m in length. Holes were drilled in the pipes to reduce their weights to desired levels.

Safadari *et al.* (2010) studied the design, construction and evaluation of a portable limb shaker for almond tree. The shaker was powered by a 2 stroke spark ignition engine. A centrifugal clutch along with a gearbox was used in conjunction with slider crank mechanism to transmit power to a limb through a boom and C-shaped clamp. To evaluate the machine performance, a factorial experiment with complete randomized design in tree replications was conducted. The factors were shaking frequency (10, 13 and 15 Hz), shaking duration (5 and 10 seconds). To calculate the ratio of fruit detachment force (F) to its weight (W), appropriate measurements were made. Also, the geometric mean diameter of the fruits was determined at different stages of maturity.

Ratnakumar (2013) studied the development of a tool for effective mango harvesting to reduce post-harvest loss. During pre-harvesting two major damages were occurred i.e. latex, bruise and blemishes. As per literature available mango with stalks intact had exhibited delayed shriveling. To avoid most of the damages caused during harvest, a tool known as DBAU (Department of Botany Andhra University) mango harvester prototype was designed with locally available materials. It consists of a plastic basket with notch, round shaped blade holder (two halfs), Detachable blades (the blades were arranged at 45^0 to facilitate easy cutting), lever to trigger the blades and a plastic pole to hold all the parts. The entire equipment weighs about 1.5 kg and 5.00 Feet in length.

Ahmed and Francesco (2014) studied the proposed harvester model for palm date fruit. The proposed machine was designed in Solid-Works computer software. This harvesting machine includes four components namely stabilizing platform, lifting device, lowering device and cutting device can be carried around manually and fixed at the base of any palm trunk and used to cut and lower whole clusters without having to climb the palm. The weight of developed equipment was about 28 Kg and this machine developed to be able to harvest clusters to 8 m of height.

Hamedon *et al.* (2008) studied the design, fabrication and testing of new invented spring sickle pole “ZappIt” for palm harvesting a new harvesting pole, specifically designed for palms trees, was designed, developed and tested. It comprises three sections, the locking, extension and spring sickle, which were joined through an aluminum pole. The pole can be adjusted to certain length to reach different height of tree. It is built using standard circular rod with cross section diameters of 50 mm. This newly invented spring sickle pole called “ZappIt” has been designed based on the ordinary sickle widely used in Malaysia palm estates. ZappIt introduced new mechanism concept of spring compression as a source of mechanical force to cut the frond and fruit bunch. The locking system was designed and located at the bottom of the pole for manual hand operated. While the threaded steel used to link the locking systems and spring sickle system.

2.3 Performance evaluation of the fruit harvesters

Anonymous (1989-a) the experiment was conducted at Bidhan Chandra Krishi Viswavidyalaya, Haringhata and Kalyani University, Nadin West Bengal for Himsager mango fruit and reported the length of stalk of harvested fruits, with local zela varied from 1 to 3.7 cm and Dapoli harvester ranged from 0.62 to 2.1 cm. Physiological losses in weight (PLW) of fruits and spoilage was found minimum in Dapoli harvester as compared to other harvesters. Spoilage of fruits due to mechanical injury was less by Dapoli harvester (14.5 %) compared to conventional harvester (22 %).

Anonymous (1994) developed Mango harvester known as "Nutan Nipper" at Dr.BSKKV, Dapoli Maharashtra. The device harvested all the fruits with pedicle avoiding injury to the fruits. It avoided jerks to the branches and hence, no loss by way of fruits drop from the tree was observed. It avoided shaking of branches and thus no mechanical injury to the branch of mango tree was observed. The device was reported to be simple and very handy because it could be operated by one person. It could harvest 450 to 500 fruits in a day of 8 hours.

Whitney *et al.* (1996) analyzed harvesting data collected during the 1993 & 1994 season for four pairs of pickers in orange trees. The results revealed that the fruit yield varied from 30 to 76 t/ha, fruit weight from 160 to 235 g and tree height from 3.7 to 5.5 m. They also concluded that the average harvesting rate per picker was ranged from 241 to 376 kg/h and the harvesting rate increased by 40.8 kg/h for an approximate increase of either 20 t/ha in yield or 50 g in fruit, or a 2 m decrease in tree height.

Anonymous (1998) made a comparative study on methods of harvesting of Alphonso mango. Four harvesting methods the developed harvester, local zela (conventional harvester), hand picking with stalk, hand picking without stalk were selected. The developed harvester harvested maximum number of fruits (168 fruits/ hour) followed by hand picking without stalk (71 fruits), Hand picking with stalk (70 fruits) and lastly by local zela (l28 fruits) per hour. Alphonso mango harvester with stalk recorded delayed ripening. Fruit harvested with the developed harvester and those harvested with stalk by hand picking recorded equal shelf life of l5 days. Followed by those harvested without stalk by hand picking (13 days) and local zela (l2 days). The developed harvester showed the maximum harvesting efficiency.

Valdez (1999) developed a mango fruit harvester to minimize damage and ease harvesting operation. The harvester consisted of a 6 m pole that could be adjusted depending on the height of the fruit to be harvested. The upper pole is 12 mm in diameter and 3 m in length while the lower pole is l9 mm in diameter and 3 m in length. The upper pole is fitted inside the lower pole and can be adjusted to desired length. A harvester ring, a basket, and a stripper are attached at the end portion of upper pole. Field test revealed that a person using a designed harvester could gather 480 to 540 fruits/hour. Existing harvesters have a capacity of 380 to 400 fruits/hour. The harvester gave about 95 undamaged per 100 fruits while existing harvester gave 84 undamaged per l00 fruits harvested.

Anonymous (2001) developed a manual mango harvesting device and evaluated at farmer’s orchard in Junagadh district. The results revealed that the maximum fruit (858/hr) harvested using the developed model followed by traditional model (740/hr). The lowest harvesting capacity was observed for second traditional model (577/hr). The results showed that the average stalk length, the most important parameter, was found to be 1.90 cm for the fruits harvested with the developed model while for second traditional and traditional models the stalk length was recorded as 4.30 cm and 7.17 cm respectively. The result also revealed that percentage of fruits harvested without stalk was highest (20.62 %) for Second traditional model and it was lowest (7.40 %) for the developed model. Safe storage period for the fruits was also determined and it was observed that fruits harvested with above equipment’s could be stored up to l0 to 11 days without showing any symptoms of spoilage. The cost of operation was found lowest (90/tonne) for the developed model.

Sapowadia *et al.* (2001) evaluated different improved models of mango harvesting: (l) Impact type; (2) Shear type; and (3) Impact cum shear type. The performance of the devices was compared with the traditional devices. The impact type model was found the best among the three models. With improved harvesting capacity, cost efficiency and less damage to the fruits. On the other hand, the shear type model could not work due to the fibrous nature of pedicle of the Kesar variety of mango. With the use of impact type model, harvesting capacity increased by 18 % and visible damage to the mango fruit was reduced by 50 %.

Sanders (2005) concluded that mechanical harvesting provides a significantly higher harvesting rate over manual picking. The maximum picking rate of manual pickers is 0.5 t/h, whereas the picking rate of trunk shaking harvesters is 10 t/h and of canopy shakers is 25 t/h. Hence, a mechanical harvester can replace 20 to 50 manual pickers. Manual harvesting offers the benefits of maximum fruit selection and maximum product quality; but has the disadvantages of uncertain labor availability and a relatively low picking rate. Also, he added that the harvesting of citrus fruit represents 35 to 45 % of total production cost. Hence, an improvement in the efficiency of this one operation has a significant effect upon enterprise viability and profitability**.**

Torregrosa *et al*. (2008) designed and tested catching systems to pick the peaches detached from the trees by shaking with hand held shakers. Three catching Systems were tested: A) a pair of canvases, B) a catching trailer with extractable flat planes and C) a pair of canvases with direct discharge to boxes. Fruit detachment percentage with the hand held shakers ranged between 83 % and 95 %. Less than 2.4 % of the fruits were severely injured. Harvesting rates per operator increased from 100 kg/h to nearly 200 kg/h with systems A and B and more than 300 kg/h with system C.

Kolhe (2010) reported that continuous increase in the yield and production rate of coconut orchards has urged the need for mechanization of coconut harvesting in India. The drudgery in manual coconut harvesting, lack of climbing labours and the operational and safety problems in availing manual climbers have necessitated the need for the mechanization of coconut harvesting. Coconut growers are facing practical difficulty in coconut harvesting due to the height of the tree. The tractor mounted hydraulic elevator (TMHE) is a fully automatic harvesting device for harvesting tall coconut orchard. The further development and testing of this elevator is in progress. The coconut harvesting capacity of the developed TMHE was observed in 4,524 coconuts/day.

Hamam *et al.* (2011-b) fabricated two mechanical harvesting prototypes (electrical picking hook and electrical picking holder) for picking Early Grand and

Meet Ghamr peach fruit varieties to compare with traditional methods of fruit harvesting (manual hand hook and manual picking methods). It was concluded that electrical picking hook gave the highest picker productivity (0.194 & 0.211 ton/h) than the manual picking method 0.129 & 0.148 ton/h followed by the productivity of electrical picking holder (0.102 & 0.110 ton/h) and the least productivity was found by manual hand hook method (0.078 & 0.086 ton/h) respectively.

Kolhe and Jadhav (2011) tested tractor mounted hydraulic elevator (TMHE) for mango orchards. It was found most suitable for harvesting and pruning of mango orchards upto l2 m tree height without affecting the stability of machine with available tools. The field capacity of elevator was 0.08 ha/h for mango harvesting. The observed field capacity of the developed TMHE was 5,400 mangos (1400 kg) per day for Alphanso mango.

Soliman *et al.* (2012) designed, fabricated and evaluated two prototypes of harvesting tools for rotary picking heads and electrical scissors harvesting head to reduce the number of manual pickers needed and maximize productivity and reduce harvesting costs. The important results were: the picker productivity was increased from 0.890 and 0.67 ton/day using traditional methods to l.663 and 1.236 tons/day for picking Washingtonin and Valencia oranges respectively, using the rotary picking cone. Picker productivity was increased from 0.890, 0.671, 0.423 and 0.102 ton/day using traditional methods to 1.029 and 1.224, 0.647 and 0.126 tons/day for picking Washingtonian and Valencia oranges, Mandarin and Lemon fruits respectively.

Patange *et al.* (2013) studied the development and comparative performance of manually operated tamarind harvesters. Traditionally farmers have been using a variety of methods in tamarind harvesting instead of tool and machinery. In India, harvesters may merely shake the branches to cause mature fruits to fall and they leave the remainder to fall naturally when ripe. By using the modern wisdom, these traditional methods needed to standardized keeping in mind the economy of rural poor. Proper designing in accordance with the farmers requirements surely popularize these harvesters in future. Keeping these views in mind design and development of various tamarind harvesters (TH1, TH2, TH3) was taken at Vasantrao Naik Marathwada Krishi Vidyapeeth Parabhani, Maharashtra and comparing their performance with traditional method (TM). On the basis of harvesting output (kg/ha), cost of operation (Rs/hr), per cent damage and ease operation, it was found that, the performance was better in case of TH3 as 10.70 kg/h, Rs 31.25/h and 10.71 per cent.

Chhotala (2014) studied the design and development of a device for black berry harvesting. The harvesting capacity of the developed device was found 4.77

kg/labour-h while the harvesting capacity of the branch shaking and hand picking method were 5.49 and 2.87 kg/labour-h respectively. The harvesting losses by the developed device, branch shaking and hand picking methods were found as l2.57, 21.45 and 9.91 % respectively. The same way the harvesting cost of developed device. Branch shaking and hand picking methods were also determined as 7.59, 5.79 and 11.11 per kg respectively.

Makwana (2016) studied the design and development of a device for harvesting of fruits from thorny trees length, width, thickness, equivalent dimmer, sphericity, weight, firmness, volume and density were observed/determined and considering these properties a common harvesting capacity, losses, cost and efficiency. Harvesting capacity losses, efficiency and cost of the developed device were found 10.05 kg/h, 6.14 % 93.86 % and 4.98 per kg for cactus pear and 10.35 kg/h, 4.78 %, 95.22 % and 5.01 per kg for Ber fruits respectively. Thus the developed device was found 32.76 % more in capacity 48.61 % less in losses 48.61 % more efficiency and 24.54 % low in cast for cactus pear and 11.05 % more in capacity, 3.5 % less in losses, 3.5 % more in efficiency and 8.585 low in cist for Ber fruits.

Savjibhai (2016) studied that development and performance evaluation of a mango harvesting device. A manually operated harvesting device was designed, developed and compared with the traditional harvesting method. The harvesting capacities of developed device and traditional harvesting device were found to be 73.33 kg/h and 55.00 kg/h up to 3 m of harvesting height and 55.66 kg/h and 44.00 kg/h beyond 3 m of harvesting height respectively. The harvesting losses of the developed device and traditional harvesting device were found to be 3.5 % and 14.90 % up to 3 m of harvesting height and 5.41 % and 26.60 % beyond 3 m of harvesting height respectively. The harvesting cost of the developed device and traditional harvesting device were found to be 0.43 Rs/kg and 0.57 Rs/kg up to 3 m of harvesting height and 0.57 Rs/kg and 0.72 Rs/kg beyond 3 m of harvesting height respectively.

2.4 Ergonomic evaluation of fruit harvesters

Prussia (1985) observed that manual harvesting had many advantages over mechanical harvesting of fruit crops. The most important advantage was visual image processing ability which enables workers rapidly to detect suitable fruits for harvesting and direct their hand to select suitable fruit for detachment, although manual harvesting has the disadvantage of low capacity. Worker positions increase the productivity by 20 to 40 % and enable to use of sun shades, fans, conveyors and other devices that increase comfort and reduce fatigue. Testing and training can yield substantial benefits from small inputs. Tests for visual acuity, colour sensitivity, strength, etc. can help managers in assigning tasks to the most suitable workers.

Sakakibara *et al.* (1995) compared orchard farmer's musculoskeletal symptoms while bagging pears with those same symptoms while bagging apples. The subjects were examined twice at evening in late June for bagging pears, and in late July for bagging apples, when each task had been almost finished. They were questioned about musculoskeletal complaints of stiffness and pain during each job and examined for muscle tenderness and pain from joint movement. Arm elevation angles during the work were measured for each type of bagging. The prevalence of stiffness and pain in the neck and shoulder, muscle tenderness in the shoulder regions and pain in neck motion were found to be significantly higher when bagging pears than apples. The working posture of elevating the arm more than 90° was assumed to account for 75 % of the time in bagging of fruits. Overhead work requiring arm elevation and head extension was considered to be closely related with shoulder-neck disorders among farmers.

Miles and Steinke (1996) modified the ladder to increase the safety and comfort for the orchard workers. Sequences of these modifications were presented to crews picking citrus. Human factors related to worker objectives, motivation and culture as well as the existing piece rate compensation system proved to be significant barriers to the acceptance of alternative ladders. They concluded the understanding of these issues as essential to engineers attempting to design alternative tools and systems to improve workers health and safety.

Fulmer *et al.* (2000) concluded on the basis of preliminary data collected on injuries bringing migrant and seasonal farm workers in farm worker health centers indicated that muscle strains are the leading category, representing 28 % of all reported injuries. On-site observations of work tasks in orchard fruit harvesting had been carried out in order to characterize the ergonomic stressors involved. The strap supporting full fruit bags creates considerable impact on shoulder tissue, while reaching and picking with both arms raised above shoulder height is observed more often than with both arms down. Placing bag contents into a bin requires an awkward and moderately forceful lift 80 to 200 kg/day, requiring severe forward flexion when the bin is less than half-full. Ladder handling is an additional stress required for semi-dwarf and full-sized trees, and ladder usage exposes pickers to fall injuries.

Maegawa *et al.* (2000) compared working postures at 30, 95, 105 and 115 cm soil bed height with different stature of the subjects for cultivation of strawberry. They found that the optimal bed height for each worker was different among the workers. They observed that the height of the elbow of the worker showed the optimal bed height.

Fulmer *et al.* (2002) concluded that the orchard work environment presents many potential sources of shoulder and back strain. The ergonomic observations made here are designed to focus research efforts to what appear to major contributors to the strain problem. Specific work elements include the static awkward postures associated with picking, carrying, and transferring the apples; the force and awkward postures associated with ladder movement and full bag handling; and the contact stress of the shoulder strap.

Richardson *et al.* (2004) adapted Posture-Activities-Tools-Handling (PATH) instruments ergonomic job analysis of apple harvest work in three New York orchards, and used the resulting protocol to quantify hazardous activities, loads, and postures using a standard prototype. The PATH data were then collected on 14 orchard workers over four days (2,900 observations). Mean coefficients of variation ranged from a low of 0.212 (standing leg neutral) to a high of 0.603 (trunk moderate flexion). Most frequently observed activities were taken viz. picking (62.9 %), placing and moving apples in the bag (8.7 %), and walking (8.1 %). Weight bearing is up to 10 lb. (4.54 kg) was observed 78.5 % of the time throughout a range of activities.

Gangopadhyay *et al.* (2005) conducted study to investigate postures adopted by preadolescent agricultural workers during individual agricultural activities and to analyze the causes of discomfort related to those postures. They randomly selected fifty male and fifty female preadolescent agricultural workers and a detailed posture analysis was performed with the Ovako Working Posture Analysis System (OWAS). Workers who worked continuously in awkward postures during certain agricultural activities were observed to suffer with discomfort in different parts of their body.

Paul *et al.* (2006) found that neck, back and shoulder musculoskeletal strain are major occupational health problem affecting orchard harvest workers. They measured the effect of an ergonomically modified apple picking bucket on muscle fatigue. They also developed simple back, shoulder or arm strength measures, which detect statistically significant drops in strength over one workday. Candidate muscle strength measures were piloted in the laboratory, adapted for the orchard and evaluated. Data were analyzed for morning to afternoon fatigue and for correlation between fatigue score and harvesting hours. In the laboratory, the timed arm hold (35.7 % time reduction), and the timed spinal extension (31.8 % time reduction) showed significant fatigue. In the orchard, only the timed arm hold showed significant (11.4 %, p<0001) fatigue.

Wade (2010) studied the ergonomic of traditional guava harvesting system. Traditional method of guava harvesting was ergonomically evaluated with 12 male agricultural workers. Ergonomically evaluation was made on the basis of ODR, BPDS, heart rate and energy expenditure rate. The ODR value ranged from 4.7 to 6.4 and BPDS (body part discomfort score) value ranged from 45 to 57 in guava fruits harvesting. The mean working heart rate (HR) ranged from 98.70 to 102.02 beats/min and mean HR value ranged from 21.00 to 26.35 beats/min for traditional guava harvesting. The mean energy expenditure rate was very high (3.39 kcal/min). Considerable damage in fruits was observed with traditional harvesting method. Overall discomfort rate (ODR) and mean working heart rate (HR) were used to classify the level as discomfort and type of work amongst the workers. Guava fruit harvesting with traditional method was observed to be moderately heavy mode of work with “fairly discomfort”.

From the above available literature, it is concluded that a number of fruit harvesters were developed in the world for apple, citrus, orange, peaches, mango etc. These harvesters/devices were hand operated as well as machine or automatic robotic picking fruits types, with the range of low capacity to high capacity. However, in India, the mostly developed fruit harvesting devices were manually operated and mostly for Mango. The fruit harvesting devices or harvesters search indicated no harvesting machine/device for Nutmeg fruit are available. The traditionally, two methods of Nutmeg fruit harvesting i.e. manually hand picking and shaking of tree branches are being used in India. The existing methods of Nutmeg harvesting are very tedious, time consuming, labour dependent and risky. The declining labour availability, increasing labour costs and combined with more awareness to health and safety issues there is an urgent need to mechanize or to improve the existing fruit harvesting operations or techniques for Nutmeg fruits.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the procedure followed and materials used for selected research. The Manual Nutmeg harvesting system was designed, developed and evaluated for its field performance. The economics of developed manual Nutmeg harvesting system is compared with existing traditional harvesting method.

3.1 Nutmeg plant characteristics

Nutmeg (*Myristica fragrans* Houtt.) produces two separate spices namely nutmeg and mace. Nutmeg is generally cultivated using mix cropping with many varieties of population and species, which is supposed to influence the characteristics of nutmeg plants. Nutmeg plantation is a mix crop between nutmeg as the main crop and other crops such as cinnamon, black paper, coconut and others. To understand the characteristics of nutmeg, especially tree height, bark height, plant to plant and row to row distance, fruit distribution pattern viz., inside, outside and top of the plant. The above nutmeg plant characteristics were measured for the design and development of manual Nutmeg harvesting system. To measure Nutmeg plant characteristics, 30 plants of 10 to 12 years old were selected. Plant height was measured using Altimeter (Plate 3.2) and while measuring plant height it was ensured that, the horizontal distance from selected plant to operator should be 20 m at ground level. A survey of Nutmeg crop at Horticulture Farm, Department of Horticulture, College of Agriculture, Dapoli was conducted to collect the information of above mentioned Nutmeg plant characteristics and observations are presented in Appendix I.

The procedure adopted for measuring fruit percentage of Nutmeg plant was as follows. Nutmeg plant was divided into different portions as shown in fig 3.1. The number of fruits in different portion was counted by visual observation and recorded. The percentage of number of fruit located in outside, inside and top portion were also calculated.

Plate 3.1 Nutmeg plants in coconut based mix crop pattern

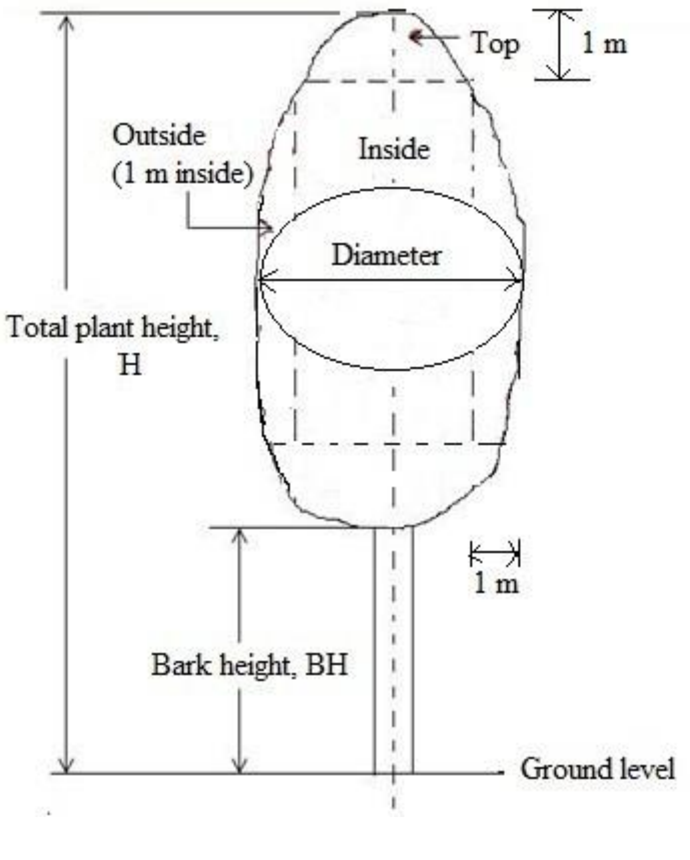


Fig 3.1 Measurements of fruit distribution and other characteristics of Nutmeg plant

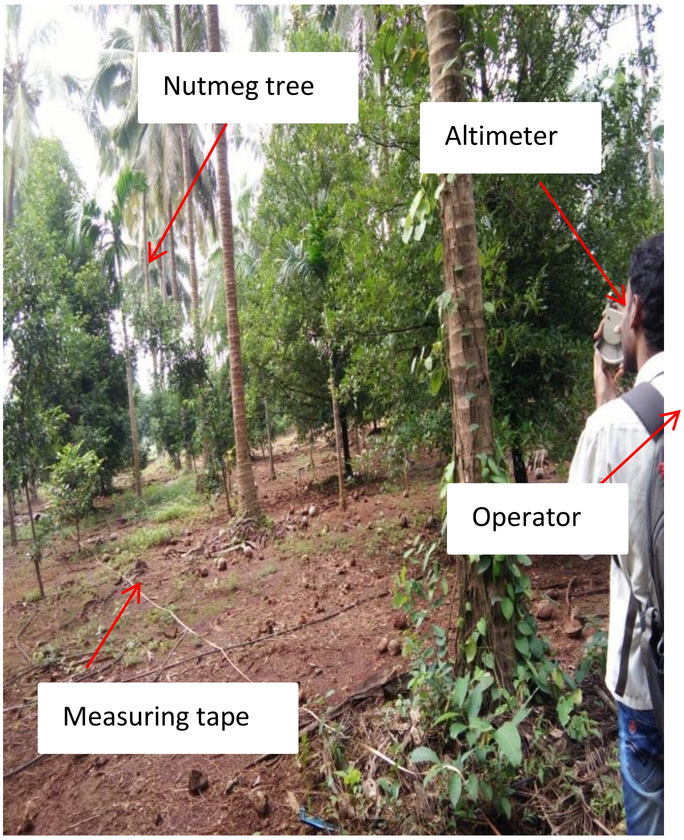


Plate 3.2 Measurement of Nutmeg plant height by Altimeter

3.2 Physical properties of Nutmeg fruit

The physical properties of Nutmeg fruit viz., length, breadth and thickness of matured fruit similarly weight of nut, mace, pericarp and whole fruit are required for development of harvesting system. The physical properties of Nutmeg fruits were measured in the laboratory of All India Co-ordinated Research Project (AICRP) on Spices, Department of Horticulture, College of Agriculture, Dapoli. The fully matured fruits were selected randomly and the following observations of individual fruits were noted. Observations are presented in Appendix II. The measurements of physical properties of Nutmeg plant are shown in Plate 3.3.

3.2.1 Fruit length

The length of sampled fruits from stalk base to the apex of fruit was measured with the help of Vernier caliper (Range 0 to 30 cm and least count 0.01 mm) in cm to find mean length as shown in Plate 3.4.

3.2.2 Fruit breadth

The maximum linear distance between two sides of the fruits was considered as the breadth and was measured with the help of Vernier caliper (Range 0 to 30 cm and least count 0.01 mm) in cm to find mean breadth.

Plate 3.3 Measurement of physical properties of Nutmeg fruit

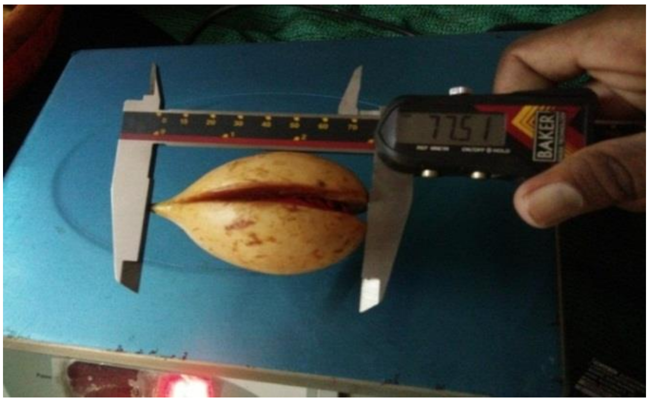


Plate 3.4 Length of Nutmeg fruit

3.2.3 Fruit thickness

The minimum linear distance between two sides of the fruits was considered on the thickness and was measured with the help of Vernier caliper (Range 0 to 30 cm and least count 0.01 mm) in cm to find mean thickness

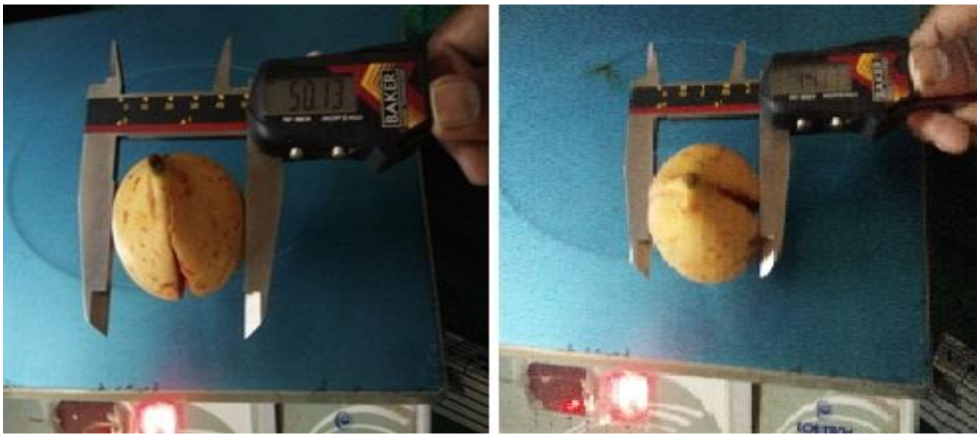


Plate 3.5 Width and thickness of Nutmeg fruit

3.2.4 Weight of fruit

Individual freshly harvested fruit was weighed on electronic balance (Range 0 to 2 kg and least count 0.1 g) in g to find mean fruit weight and moisture content of fruit was found out on wet basis in per cent by oven dry method.

Plate 3.6 Weight of fully matured Nutmeg fruit

3.2.5 Weight of nut

The weight of above selected nuts was measured on electronic balance (Range 0 to 2 kg and least count 0.1 g) in g to find mean weight of nut and found out the moisture content of nut on wet basis in per cent by oven dry method.

3.2.6 Weight of mace

The mace was separated from the fruit and weighed individually on electronic balance (Range 0 to 2 kg and least count 0.1 g) in g to find mean weight of mace and moisture content was found out on wet basis in per cent by oven dry method.

3.2.7 Weight of pericarp

The weight of pericarp was calculated by subtracting the weight of Nutmeg fruit and weight of nut and mace for the respective fruits and recorded in g and found out the moisture content of pericarp on wet basis in per cent on oven dry method.

3.3 Engineering properties of Nutmeg fruit

For the purpose of development of manual Nutmeg harvesting system following engineering properties viz., size or equivalent diameter or geometric mean diameter, sphericity, unit volume, projected area, surface area and bulk density were determined with the help of different formulae as follows. Observations are presented at Appendix II. The three different crop varieties were selected for measurement of engineering properties viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri. The above mentioned engineering properties of Nutmeg fruit was measured in the laboratory of AICRP on Spices crops, Department of Horticulture, College of Agriculture, Dapoli during last week of August 2017.

3.3.1 Size or equivalent diameter or geometric mean diameter

Size or equivalent diameter is the geometric mean of the three dimensions viz., length, breadth and thickness (Mohsenin, 1950). The size was calculated by using following relationship:

$$\emptyset = 3\sqrt{\mathrm{LBT}} \quad \ldots (3.1)$$

Where,

∅= Size or equivalent diameter

L= Length (Major diameter)

B= Breadth (intermediate diameter)

T= Thickness (minor diameter)

3.3.2 Sphericity

The shape of Nutmeg kernel resembles like that of ellipsoid. The volume of the solid was assumed as equal to the volume of the triaxial ellipsoid with intercept L, B, T and that the diameter of the circumscribed sphere is the longest intercept (L) (Mohsenin, 1950), the degree of sphericity was determined with the help of following formula.

$$\mathrm{S} = \sqrt[3]{\mathrm{LBT}}/\mathrm{L} \quad \ldots (3.2)$$

Where,

S= Sphericity

L= Length (Major diameter)

B= Breadth (intermediate diameter)

T= Thickness (minor diameter)

Also, Sphericity = Geometric mean diameter/Major Diameter

3.3.3 Unit volume

Unit volume of individual fruits was determined from the values of L, B and T using the formula proposed by Millar, 1987.

$$\mathrm{V} = \pi\frac{\mathrm{LBT}}{6} \quad \ldots (3.3)$$

Where,

V= Unit volume

L= Length (Major diameter)

B= Breadth (intermediate diameter)

T= Thickness (minor diameter)

3.3.4 Projected area

The projected area of the fruits was found out by equation proposed by Li *et al.*, (1998). This was investigated by using unit volume above as,

$$A_p = kV^{2/3} \quad \ldots (3.4)$$

Where,

A_P= projected area

V= Unit volume

(k= constant,1.21)

3.3.5 Surface area

The surface area of Nutmeg fruit was calculated with the help of the following formula given by Li *et al.*, (1998).

$$(A_s) = (36\,\pi)^{1/3} \times (V)^{2/3} \quad \ldots (3.5)$$

Where,

A_s= Surface area

V= Unit volume

3.3.6 Bulk density

Bulk density was determined by filling a specific mass of sample in known volume of rectangular box. The sample was weighed which required for filling the box. The bulk density of Nutmeg fruit expressed as below (Mohsenin, 1950).

$$\text{Bulk density} = \text{Weight of material/Volume of material} \quad \ldots (3.6)$$

Plate 3.7 Measurement of bulk density of Nutmeg fruit

3.4 Determination of fruit detachment force

To know the detachment force required for detaching the matured (i.e. pericarp split opened) and unmatured (i.e. pericarp not spilt opened) Nutmeg fruit with respective to weight for the purpose of development of manual Nutmeg harvesting system. Fruit Detachment Force (FDF) per unit weight (W) of the Nutmeg was measured at the time of maturity level of Nutmeg between the last week of August and first week of September 2017. To measure the fruit detachment force, the load cell (Range 0 to 40 kg and least count 0.1 g) was attached to the fruit detacher. The arrangement of load cell measuring FDF is shown in Plate3.8 and 3.9.The respective weights of the Nutmeg fruit harvested were measured on the electronic balance. Observations are presented in Appendix III and the average FDF per unit weight were calculated.

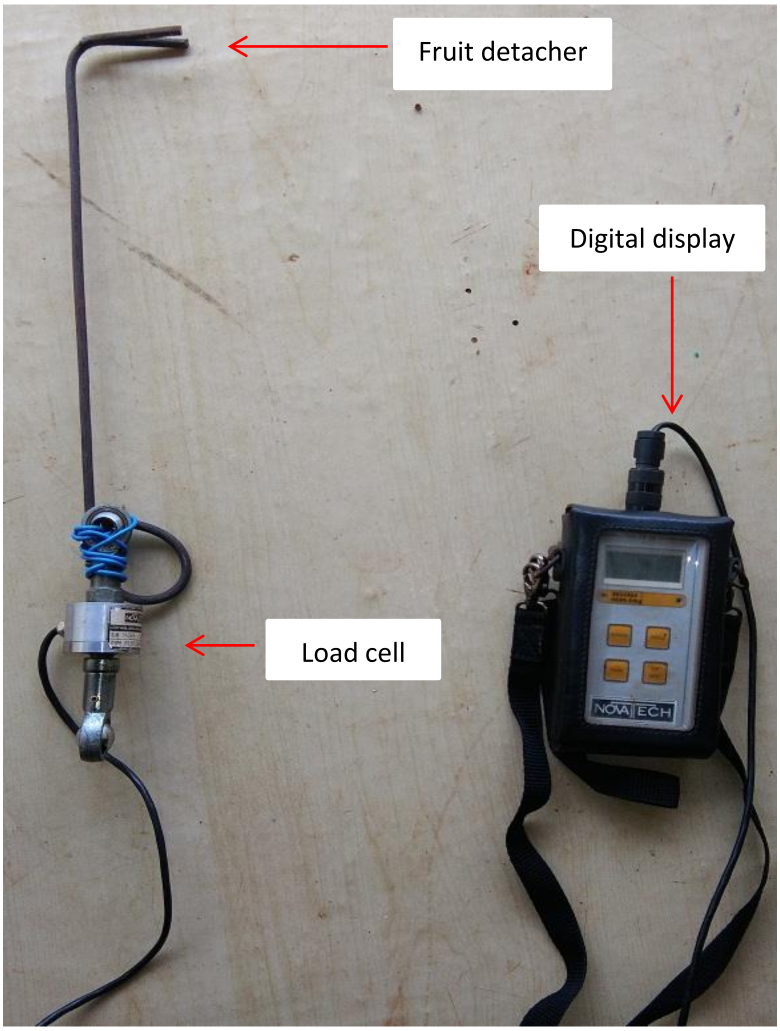


Plate 3.8 Load cell arrangement for measurement of fruit detachment force (FDF)

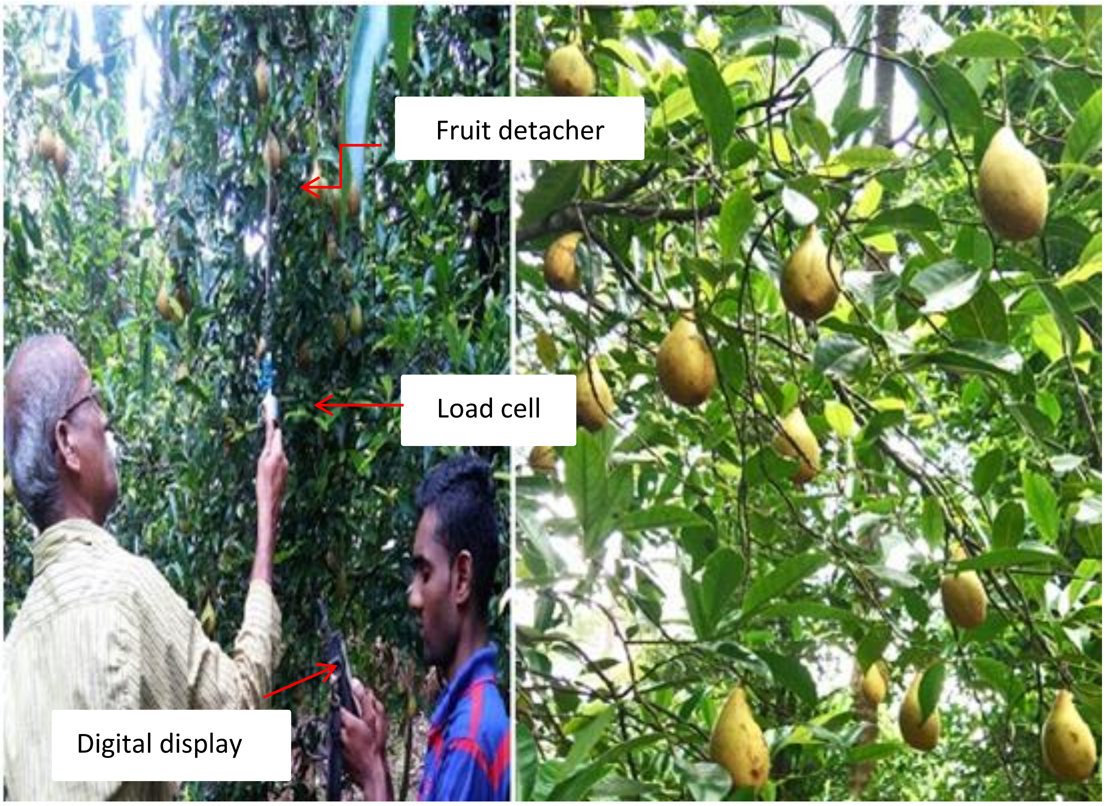


Plate 3.9 Measurement of fruit detachment force by using load cell (Range 0 to 40 kg and least count 0.1 g)

3.5 Location of experiment

A Nutmeg harvesting device was designed and fabricated in the workshop of the department of Farm Machinery and Power (FMP), College of Agricultural Engineering and Technology (CAET), Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth., Dapoli. Performance evaluation of developed manual Nutmeg harvesting system was carried on the farm of Department of Horticulture, Dr. BSKKV, Dapoli and farmer's field at Murdi, Anjarle, Kelashi, Burondi Villages of Dapoli tahasil, Dist- Ratnagiri.

3.6 Design considerations

The following assumptions were made to design a manually operated harvesting device/system for Nutmeg fruit.

1. Single operator should handle the device easily with minimum efforts to harvest and collect the fruit.
2. The device should be simple in design construction and requires minimum repair and maintenance.
3. The handle length of the device should be telescopic, so as increased or decreased the length as per requirements.
4. The length of the telescopic pole should be 2 to 4 m.

5. The Nutmeg plants do not have strong branches and operator can not climb on branches to harvest fruit or other operation. Considering the plant characteristics, the minimum height of harvesting platform should be 2.5 m from ground level for maximum fruit harvesting.
6. The device should be low in cost, small in size and light in weight for system ease of operation and transport by operator.
7. The harvesting time, time loss during harvesting and total harvesting time should be minimum.
8. The fruit damage during harvesting should be minimum.
9. All part should be easy to assemble and dissemble for transportation from one field to another.

3.7 Development of manual Nutmeg fruit harvesting system

Newly developed manually operated Nutmeg harvesting system consists of fruit harvester, telescopic pole, harvesting platform and fruit collecting basket. Development of newly developed harvesting system was based on above design considerations, Nutmeg plant characteristics, physical and engineering properties of Nutmeg fruit, anthropometric measurements of agricultural worker and economics of farmer specially in Konkan region of Maharashtra state (India). The fruit harvester is fitted with telescopic pole by nut bolts for harvesting fruit from ground surface as well as from harvesting platform. The height of telescopic pole can be increase or decrease as per the requirement for harvesting fruit. The fruits on top portion of the tree were harvested by using harvesting platform with telescopic pole. The harvested fruits were collected on fruit collecting basket and after harvesting the harvested fruits was transported from field to store house or further process by fruit collecting basket. The detailed development of manual Nutmeg harvesting system as discussed below.

3.7.1 Fruit harvester

The mainframe of developed fruit harvesting tool are consists of circular ring, connector, V-shape picker hook and fruit collection net.

3.7.1.1 Circular ring

To finalize the diameter of circular ring, the physical properties viz., dimensions of fruit (L, B and T), weight of fruit and bulk density was considered. At a time, 8 to 10 fruits may be harvested weighing 500 to 600 g and 300 to 350 cc volume based on bulk density of matured fruit. Also fruit should not spill away from fruit harvester. Hence, the diameter of ring of fruit harvester has been finalized as 200 mm, was made from mild steel rod 8 mm diameter. One end of circular ring was connected to connector and supporting rod of picker hook (Fig 3.2).

3.7.1.2 Connector

Connector was provided for connecting the circular ring, supporting rod of picker hook and telescopic pole fit with nut and bolts. Connector was made from hollow pipe of mild steel having diameter 20 mm×3 mm thickness×80 mm length.

3.7.1.3 V-shape picker hook

Nutmeg fruit harvesting require simply pulling action rather than cutting or shearing action and only pulling mechanism is required to harvest the Nutmeg fruit rather than cutting and shearing. To finalize the V shape picker hook of fruit harvester, the physical properties viz., length, breadth and thickness of fruit was considered. In addition, fruit detachment force was considered while finalizing the thickness of the V shape picker hook of fruit harvester. Developed harvesting mechanism consists of two blades i.e. V-shaped picker hook (65 mm length×8 mm width×3 mm thickness). It was attached to circular ring with the help 8 mm diameter of supporting rod at two places. The angle between two blades of V-shaped picker hook is 35^0 and finalized on the shape and location on fruit attached to the small branch of the Nutmeg plant. The V shape picker hook is located at center, 110 mm height from circular ring and supported by support rod at one end and connector at other end.

3.7.1.4 Fruit collection net

Fruit collection net was used to collect the fruits after being detached from tree and to avoid the damage of Nutmeg fruit due to falling on the ground. The physical properties viz., shape, length, breadth, thickness and weight of matured Nutmeg fruit was considered while finalizing the fruit collection net to the fruit harvester. Also engineering properties viz., unit volume and bulk density was considered to finalize the capacity of fruit collection net. The capacity of fully loaded fruit collection net is 8 to 10 matured fruit. It is made of nylon wire 1 mm diameter with 20 mm space and tied at the bottom of fruit catcher (plate 3.10). To avoid spillway of fruit harvested, backside of hook was closed by cotton cloth.

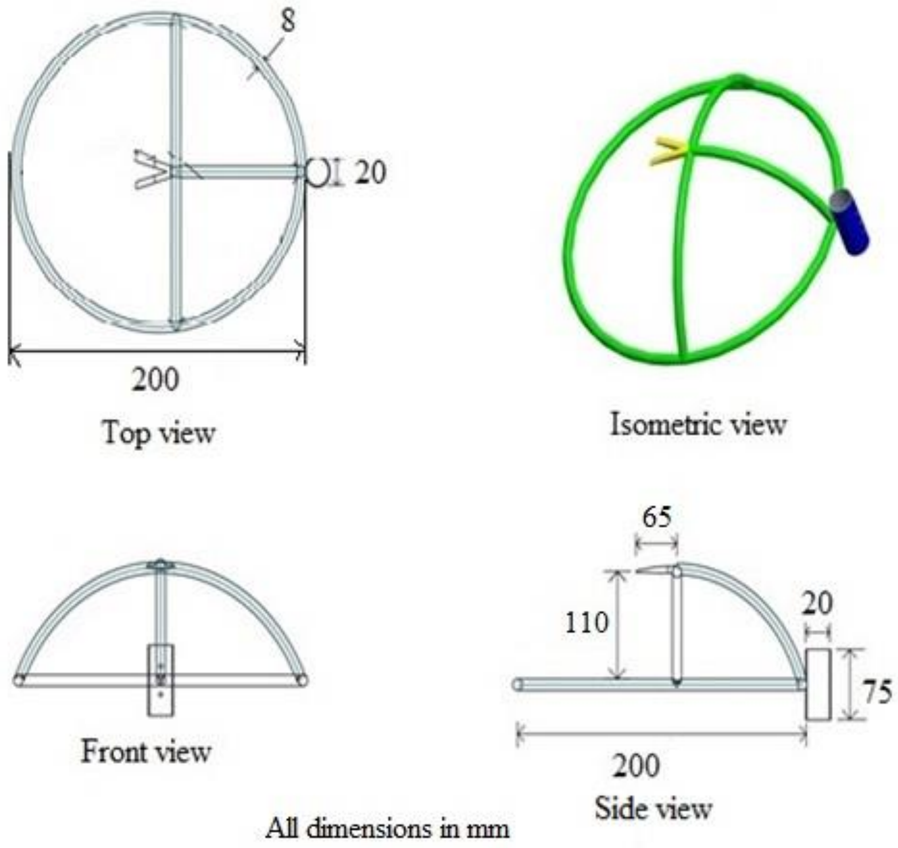


Fig 3.2 Fruit harvester of manual Nutmeg harvester

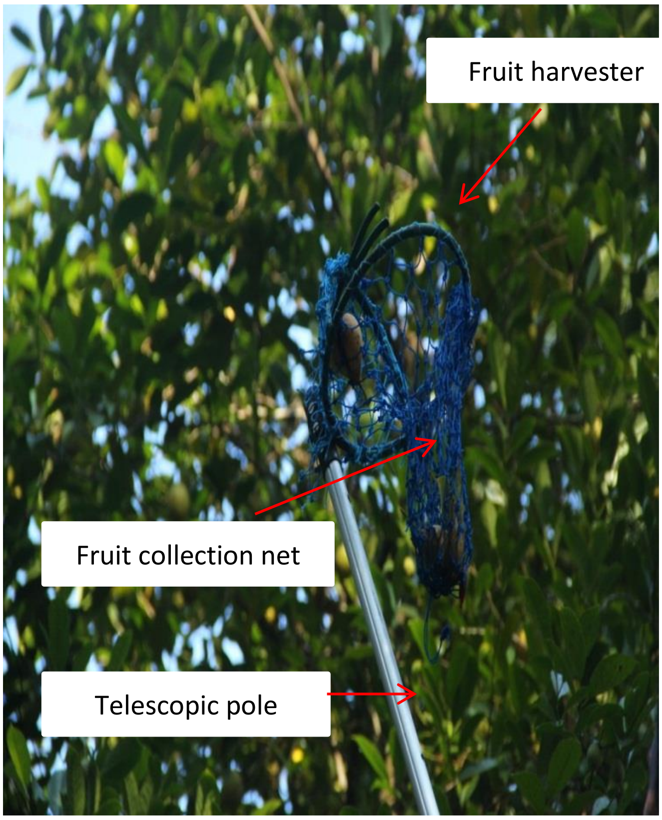


Plate 3.10 Fruit collection net tied at the bottom fruit catcher and telescopic pole

3.7.2 Telescopic pole

3.7.2.1 Theoretical design consideration of telescopic pole

Following were the main criteria considered in the design of the harvesting pole.

1. Lightweight - for easy handling
2. High stiffness - to reduce deflection especially during lifting
3. Rustproof - to last longer
4. Hard - to prevent denting
5. Ergonomic - for comfortable hand gripping
6. Strength and durability

Considering the material strength, light weight and easy for operator, two different sizes of round aluminum hollow pole (pipe) were selected having 20 mm, 25 mm and 25 mm diameter and 1.4 m, 1.4 m and 1.2 m length respectively. Three parameters were taken into design consideration viz. cross-sectional shape, cross-sectional diameter and combination of length. The reason for choosing circular shape of telescopic pole was to increase the contact surface area for better hand gripping. Aluminium alloy was selected for fabrication as it was light in weight and offered the desired characteristics such as strength and durability. The respective outer and inner diameters of pole were similar for basal and middle section i.e. 25 mm × 21 mm while the top portion was smaller in cross section with outer and inner diameter as 20 mm × 16 mm. The telescopic arrangement was done only in between middle and top section of the pole. These dimensions maintained the integrity of the pole and improved the pole stiffness as well as resulted in least buckling of pole. The cross section of basal, middle and top pole is shown in fig 3.3.

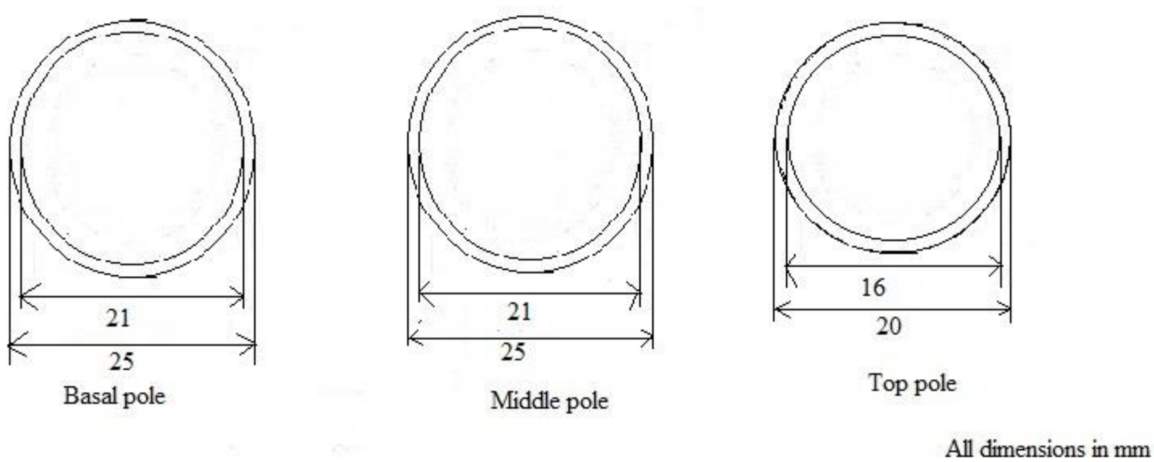


Fig 3.3 Cross sectional dimensions of developed harvesting telescopic pole

The top section of the pole was 2 mm thick and had two grooves along length to avoid twisting and this increased the pole stiffness thus preventing the pole from buckling. The fruit harvester to attached to the free end i.e. the top section of telescopic pole while the other end held in the operator's hand. During harvesting operation, as the fruit collection net with harvested fruits, some buckling may be observed due to loaded weight of fruit in collection net at the free end. This effect is quantified in the following section.

3.7.2.2 Buckling of telescopic pole

When a structure is subjected to compressive stress, buckling occurs. Buckling is mathematical instability that leads to failure mode. This may occur even though the stresses that develop in the structure are well below those needed to cause failure of the material of which the structure is composed. As applied load is increased on a member, such as a pipe, it will ultimately become large enough to cause the member to become unstable and it is said to have buckled. Further loading will cause significant and somewhat unpredictable deformations, possibly leading to complete loss of the member's load-carrying capacity (Anonymous, 2018).

The buckling of telescopic pole due to its self-weight was calculated as the ratio of actual length to its critical buckling length i.e. the maximal length it could reach with the same volume of material, taking its developmental constraints (weight, length and material properties of telescopic pole) into account (Jaouen *et al.*, 2007).

The following formula was used to calculate the Euler's crippling load also called as Euler's buckling load for one fixed end and other end was hinged (Anonymous, 2018).

$$P_E = \pi^2 E I_{min} / (L_e)^2 \quad \text{....(3.7)}$$

Where,

P_E = Euler's buckling load, N

E = young's modulus of aluminium, 0.69×10^5 N/mm^2

I_{min} = minimum moment of inertia, mm^4 = I_{xx}=I_{yy} = $(\pi/64) \times (D^4-d^4)$

L_e = Effective length, mm = (Total length/$\sqrt{2}$)

The detailed cross section of hollow aluminium pipe is shown in fig 3.4.

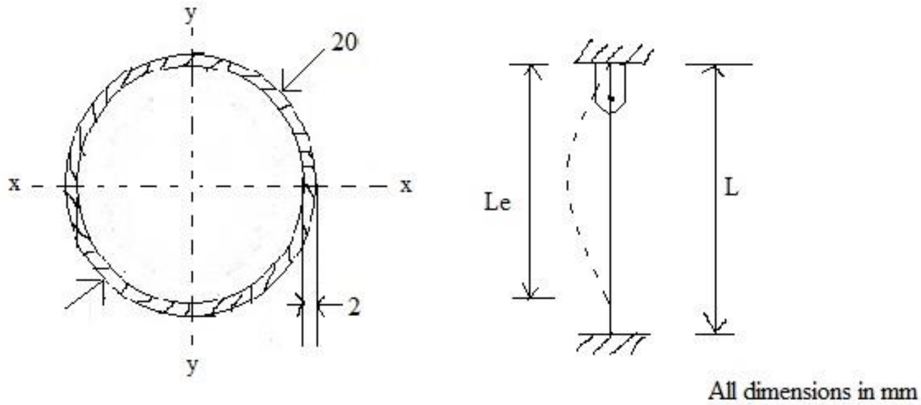


Fig 3.4 Cross section of hollow aluminum pipe

For safe load on operator's hand grip, factor of safety was considered as 4. It was observed that the calculated value of buckling load was 98.5 N (10.04 kgf). For 10 kgf load, % MVC is 8 % which is within safe limit. The Maximal Voluntary Contradiction percentage (% MVC) generated by the muscles of the forearm, spine and neck is directly proportional to the force generated by the muscles and burden resulting from the performed work (Kuta *et al.* 2015). This buckling load on telescopic pole upto 4 m length at operator hand grip was within the safe limits. Hence, the operator can perform Nutmeg fruit harvesting operation with comfort.

3.7.2.3 Shear force and bending moment for telescopic pole

The bending moment at the cross section of beam was defined as the algebraic sum of the moment of forces to the left or right of the section. Whenever a horizontal telescopic pole was loaded with vertical loads, sometimes it bent due to the action of the loads. The amount with which the telescopic pole bent, depended upon the amount and type of load, length of the pole, elasticity of pole material and the type of pole. A telescopic pole fixed at one end (i.e. operators hand) and free at the other end is known as cantilever as shown in fig 3.5.

The following points were considered for drawing the shear force and bending moment diagrams.

1. The positive values of shear force and bending moment were plotted above the base line, and negative below it.
2. If there was a vertical load at a section, the shear force diagram increased or decreased suddenly i.e. by a vertical straight line at the section.
3. If there was no loading at the section, the shear force did not change at the section, or in other words, the shear force between any two vertical loads remained unchanged i.e. shear force diagram was horizontal. The bending moment diagram was inclined.

4. The bending moment of the free end of a cantilever and two supports of a simply supported beam was zero.
5. The bending moment diagram consisted of either straight line or smooth curves.

Load acting at a point on a beam was known as concentrated or point load at the free end (i.e. weight of fruit harvester, 530 g and fully loaded fruit collecting net, 670 g) as shown in fig 3.5 and weight of pole sections as uniformly distributed load.

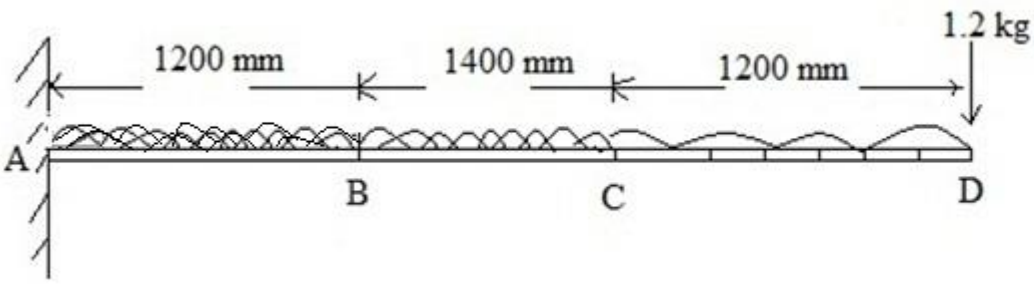


Fig 3.5 Cantilever with a uniformly distributed load and point load at the free end representing developed telescopic harvesting pole

The shear force for cantilever beam was calculated as given below and complete shear force diagram is shown in fig 3.6.

F_D = +1.2 kg

F_C = 1.2 + 0.25 = +1.45 kg

F_B = 1.2 + 0.25 + 0.37 = +1.82 kg

F_A = 1.2 + 0.25 + 0.37 + 0.65 = +2.47 kg …(plus sign due to right downward)

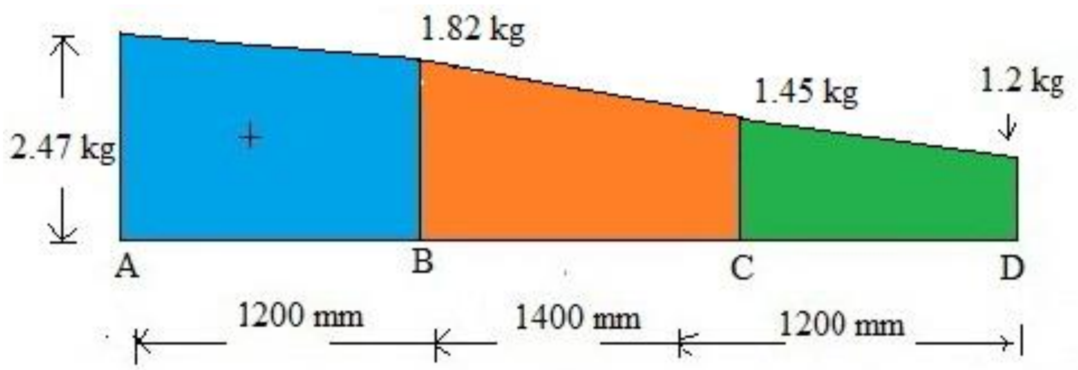


Fig 3.6 Complete shear force diagram for telescopic harvesting pole

Bending moment was zero at *D*, and increased to –1.74 kgm by a straight line low at *C*. The bending moment further increased to –4.28 kgm by a straight line low at *B*. It further increased to –7.25 kgm (minus sign due to hogging) by a straight line low at *A*. Now complete bending moment diagram as shown in fig 3.8.

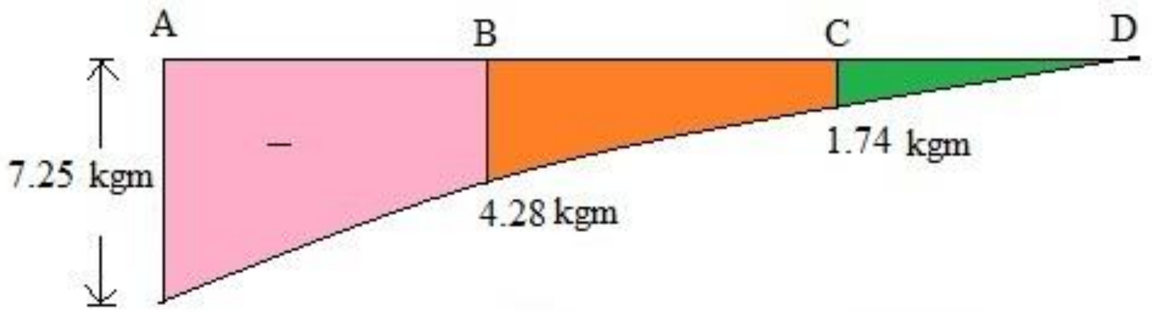


Fig 3.7 Bending moment diagram for telescopic harvesting pole

3.7.2.4 Determination of centre of gravity, deflection, weight of telescopic pole and lifting moment

The centre of gravity is the centre of weight of pole. It is found that telescopic pole with harvester at a distance of 2.21 m from base and 1.71 m from top of pole. The deflection of pole is observed when the harvester is hanged at free end of telescopic pole as shown in fig 3.8. The deflection of telescopic pole, telescopic pole with harvester and telescopic pole with fully loaded fruit collection net were found to be 8 cm, 25 cm and 44 cm respectively at free end. In addition, deflection at CG point of telescopic pole, telescopic pole with harvester and telescopic pole with fully loaded fruit collection net were found to be 0.5 cm, 9 cm and 18 cm respectively. The weight of telescopic pole and harvester was measured on electronic weighing balance (Range 0 to 50 kg and least count 0.1 g). It is observed that the weight of basal, middle and top pole are 640, 380, 250 g and weight of harvester was 530 g. The lifting moment is defined as the product of the total weight and the distance of centre of gravity from the base of the pole. Lifting moment for telescopic pole found to be 4.02 kgm (with harvester) and 5.34 kgm (with fully loaded fruit collection net). Deflection and lifting moment are two important parameters where as they are oppose to each other i.e. deflection is inversely proportional to lifting moment. The distribution of weight is nearer to base of pole. In general, the telescopic pole physical characteristics had a significant effect on the parameters centre of gravity, deflection, weight of telescopic pole and lifting moment as studied by Jelani *et al.* 1998.

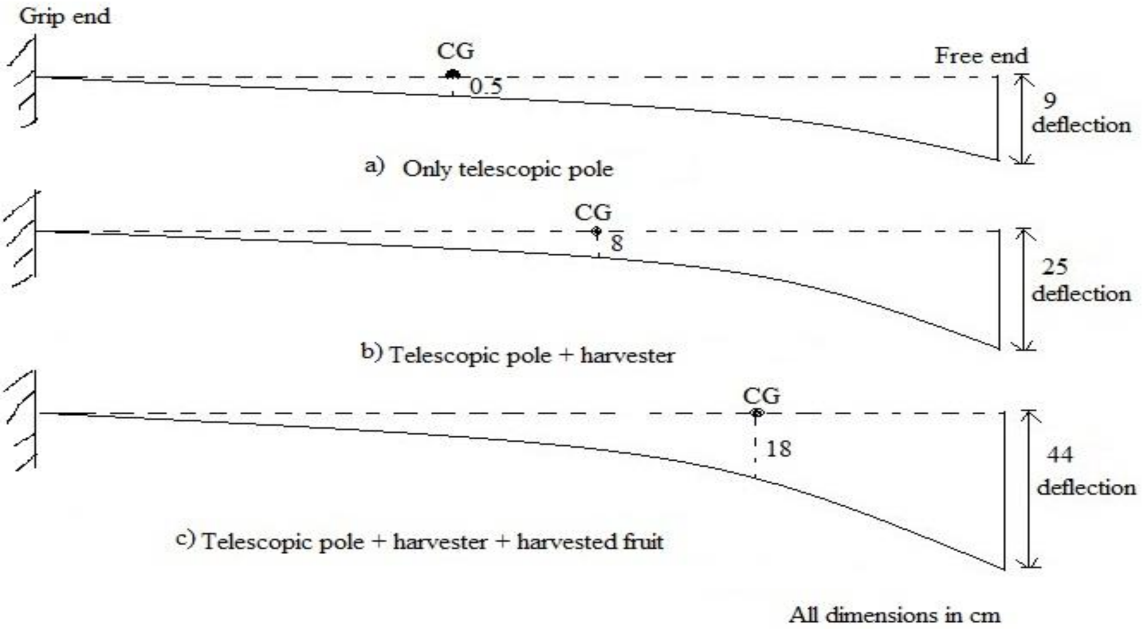


Fig 3.8 Measurement of deflection of developed telescopic pole, telescopic pole with harvester and telescopic with fully loaded fruit collection net

The deflection of developed telescopic harvesting pole is lower if compare to similar type of aluminium harvesting pole deflection used for harvesting oil palm as reported by Jelani and Hitam, 2000. The maximum lifting moment is also with safe operation limit with comfort.

3.7.2.5 Dimensions of prototype of telescopic harvesting pole

Considering the material strength, light weight and easy for operator, two different sizes of round aluminum hollow pole (pipe) were selected having 20 mm, 25 mm and 25 mm diameter and 1.4 m, 1.4 m and 1.2 m length respectively. The diameter of the grip should be such that while holding the handle, the operators largest finger should not touch the palm. At the same time, the grip should not exceed the internal grip diameter. Handle grip diameter was selected on 95th percentile middle finger palm grip diameter of male workers i.e. 38 mm, the recommended handle grip diameter is 30 to 35 mm whereas selected grip diameter is 30 mm to hold the telescopic pole comfortably (Anonymous 2013). The telescopic pole of developed manual Nutmeg harvester as shown in Fig. 3.9 and plate 3.11. A push back type button is provided between the upper and middle telescopic pole for the purpose of increasing or decreasing the length of telescopic pole as per the requirement during harvesting and locking. The minimum and maximum length of telescopic pole is 2 to 4 m.

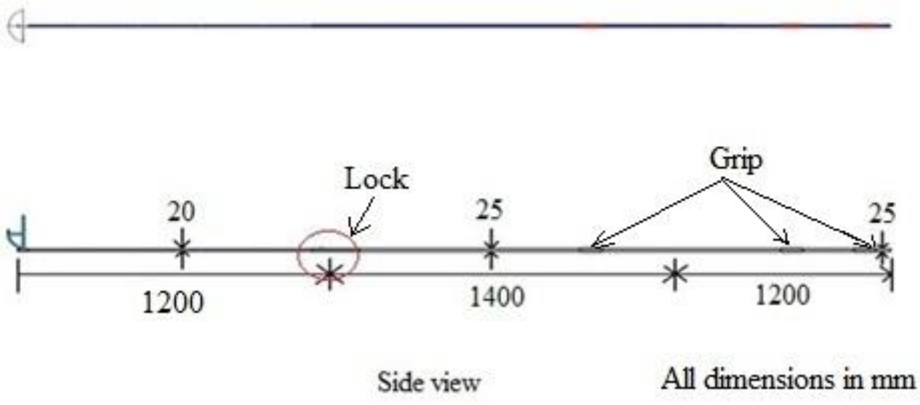


Fig 3.9 Telescopic pole of manual Nutmeg harvester

Plate 3.11 Exploded view of push button lock of telescopic pole

3.7.3 Harvesting platform

Orchard ladders, also called harvesting platform, were commonly used for fruit picking and tree pruning. Orchard ladders were not the general purpose ladders and were used for tree harvesting and pruning tasks. With proper use, ladders were indispensable tools on the farm. The portable harvesting platform was planned to use along with harvesting tool to harvest matured Nutmeg fruits located at top portion of the tree. The nutmeg plants did not have strong branches and operator could not climb on the branches to the harvest fruits. Thus, the following theoretical consideration and anthropometric measurements of agricultural worker in Konkan region were undertaken for the design of harvesting platform.

1. To suit the harvesting of Nutmeg fruit grown in a mixed cropping pattern (closely spaced) tree height limited to 8.2 m.
2. Maximum working height considering the average height of Nutmeg plant 8.2 m, the telescopic light weight pole of maximum 4 m length and the average operator height 1.5 m, platform height should be 2.66 m to harvest the Nutmeg fruit from farthest portion of the tree.

3. Set-up angle should not less than 77^0 for stability (Anonymous, 2015).
4. Total base width should be 1750 mm.
5. Dimensions of top cap should be 610 × 610 mm for standing on top cap to harvest fruit (Anonymous, 2009).
6. Height of safety guard should be 610 mm from top cap equivalent to the 5^{th} percentile of operators III metacarpal height for holding the safety guard by operator.
7. Operator need to feel secure and safe while harvesting platform.
8. The distance between two steps of harvesting platform should be 300 mm (Anonymous, 2018) for comfortable climbing on the platform.
9. Safe neck angle (40 to 50 degree) should be considered for reducing the drudgery.
10. Maximum working load on top cap of platform shall be 100 kg (weight of operator + weight of fruit harvested).

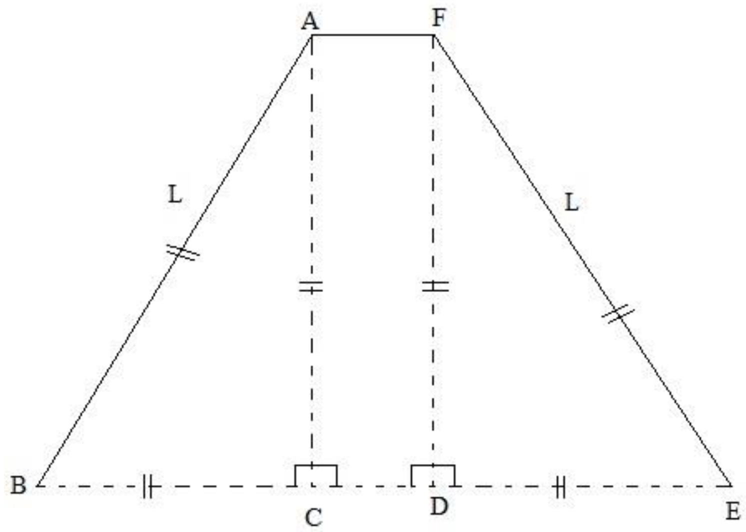


Fig 3.10 Theoretical design consideration of harvesting platform

ΔACB and ΔFDE (fig 3.10) are representing the harvesting platform.

Where,

L = Working length, mm (2730 mm)

BC and DE = set back length for ΔACB and ΔFDE respectively, mm

AF = Top cap (standing), mm

CD = base of top cap (standing), mm

BE = total base width of platform, mm

Working length (L) of ΔACB = 2730 mm

$$AC^2 = AB^2 + BC^2$$

$$BC^2 = AB^2 - AC^2$$

$$BC = 614 \text{ mm for } \Delta ACB$$

Similarly, working length and set back length are same for ΔFDE as these two triangles are similar. The total base width of platform,

$$BE = BC + CD + DE$$
$$= 614 + 550 + 614$$
$$= 1778 \text{ mm (say 1750 mm)}$$

As per U.S. Occupational Safety and Health standard 1910.23 for ladder, the steps on ladder were spaced between 20 cm to 30 cm as measured between columns of the steps (Anonymous, 2018). Height of safety guards was considered based on metacarpal III height of Indian agricultural worker which was between 501 to 930 mm and for Maharashtra state, it ranged between 570 to 804 mm. Therefore, 610 mm height of safety guard for harvesting platform from base of top cap was considered. The width between two steps was decreased by 37.5 mm from bottom to top to make it convenient for the operator to climb easily.

There was no relation between the ladder length and weight capacity. So the ladder with longer reach didn't necessarily had higher weighing capacity or higher accepting working load. The developed harvesting platform was checked for its acceptable workload by considering anthropometric data on weight of male agricultural workers of Konkan region. The 95th percentile value of male weight was 65.9 kg as given in Appendix IV. Also, the capacity of fruit collecting basket was determined based on bulk density of fruit which was 11 kg. Thus, the total weight of operator along with the fruit collecting basket was summed up as 77 kg. This total weight was equally distributed on all rail cross sections of harvesting platform. It helped in attaining stability, prevented the bending of rail cross sections as aluminium material of the platform had a good tensile strength. The load on each rail cross section of platform was found to be less than 20 kg. As per OSHA, maximum working load on top cap of the platform should be 100 kg. Hence, the acceptable workload of the developed harvesting platform was within the acceptable limit and found to be safe. The developed harvesting platform came under I type category of ladder on the basis of height, purpose and occupant loads upto 250 lbs of the harvesting platform (Anonymous, 2018).

As presented by Murrell, 1963, the safe neck angle should be in the range of 40^0 to 50^0. The height of harvesting platform is 2.7 m. The neck movement of operator is within to safe limit while harvesting fruit from top portion. The head movement to right or left is only 55^0. Although the head will bend forward 40^0 (flexion) and backward 50^0 (hyperextension) and lateral movement of head in right hand and left hand side is 40^0.The schematic presentation of head movement as shown in fig 3.11.

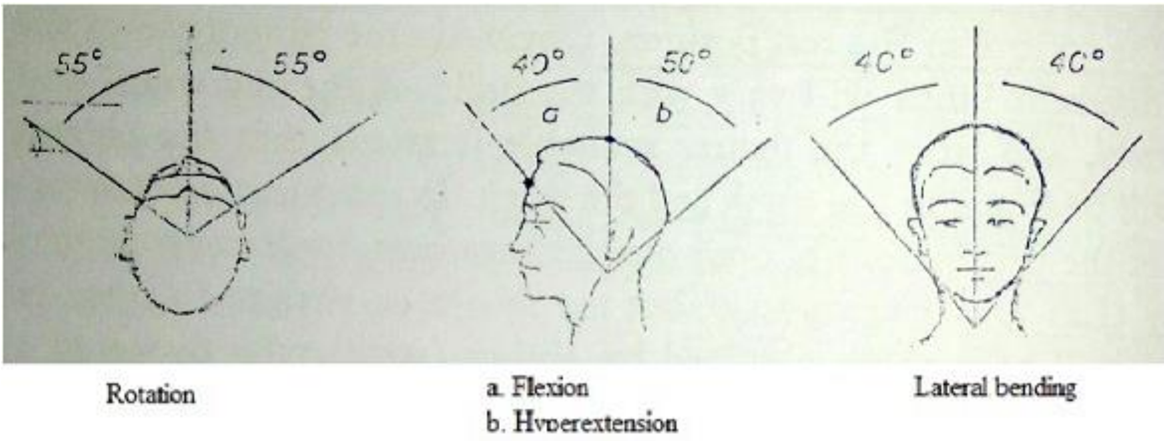


Fig 3.11 Movement of head of operator

Considering the tree characteristics, distribution of fruit on tree, the height of harvesting platform need to be 2.66 m from ground level. Planed harvesting platform is a combination of two main square sections (base section) being pivotally interconnected by employing a cross sectional 5 mm thick aluminium flat. Aluminium material is light in weight, easily available, lower cost and hence selected for fabrication of platform. The detailed view of manual Nutmeg harvesting Platform is shown in Fig 3.13. Each section was fabricated in a conventional manner with a plurality of interconnecting transverse spaced rungs. The distance between two steps of harvesting platform was kept 300 mm and it made of rectangular hollow aluminium pipe (25×37.5× 1.5 mm). The top cap (610 × 610 mm) was provided for standing of worker with providing safety guard to the harvesting platform. Height of safety guard kept 610 mm from top base, it consists of hollow aluminum square pipe (25 × 25 mm) and cross section of high tensile aluminium alloy is 67 × 31 × 2.5 mm having ultimate tensile strength 9.0 kg/mm^2. All the parts of harvesting platform consist of aluminum material to be light in weight and easy for transportation from one tree to other tree and from one field to another field.

All parts are fixed with the nut bolts and rivets. The weight of developed harvesting platform is 22 kg. The developed harvesting platform is easy to assemble and dismantle for transportation and repair maintenance purpose. The dimensions of harvesting platform are presented in Table 3.1.

Table 3.1 Dimensions of harvesting platform for Nutmeg harvesting system

Sr. No.	Particular	Dimensions
1.	Height of platform, mm	2660

2.	Dimensions top cap (standing), mm	610 x 610
3.	Base width of platform, mm	1750
4.	Distance between two straps of platform, mm	300
5.	Height of safety guard from base, mm	610
6.	Material of harvesting platform	Aluminium pipe and C profile
7.	Weight of harvesting platform, kg	22

3.7.3.1 Checking for load carrying capacity

The harvesting platform was checked for its load sustainability. For this purpose, the cross section of harvesting platform was considered which was a “C” section. The rail cross section of harvesting platform is shown in fig 3.12.

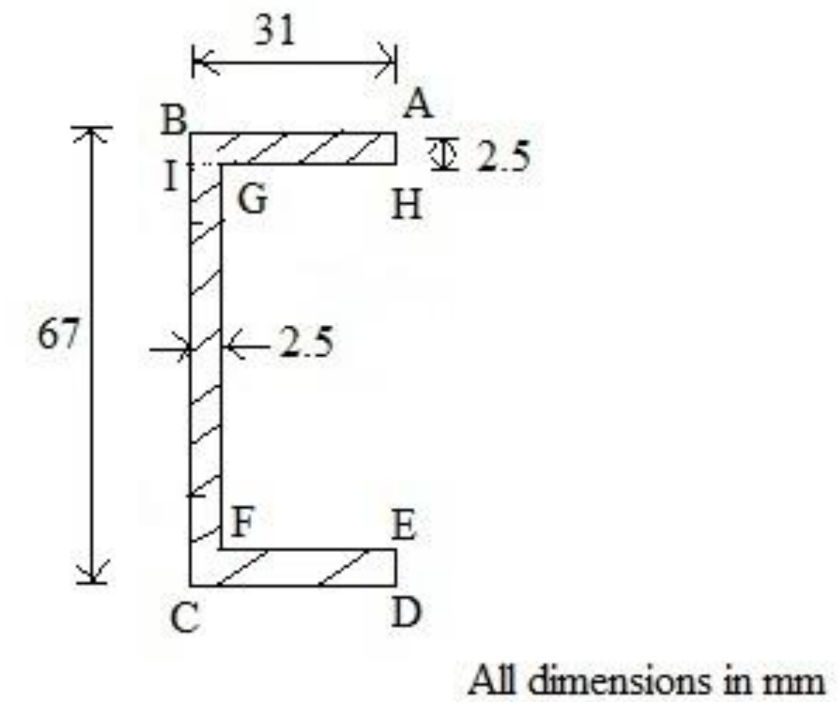


Fig 3.12 Cross section of rail of harvesting platform

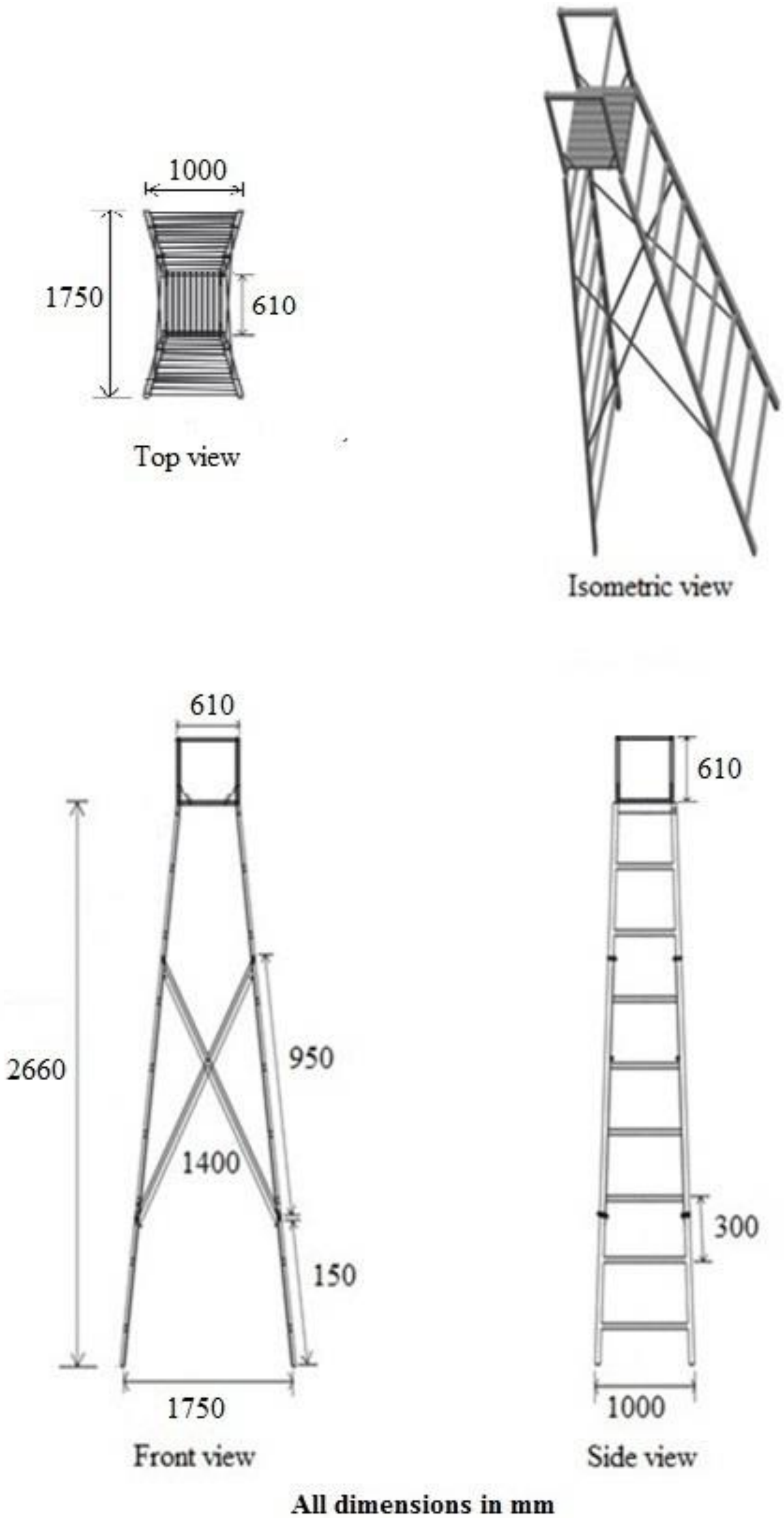


Fig 3.13 Harvesting platform

The dimensions of rail cross section of harvesting platform were 67 mm × 31 mm × 2.5 mm thereby having an area of 310 mm^2. The ultimate tensile strength of aluminium is 9.0 kg/mm^2. The maximum working load on harvesting platform was considered as 120 kg includes weight of operator, weight of harvester and weight of fully loaded fruit collecting basket. The maximum work load on the harvesting platform was calculated to be 120 kg. The distribution of this load can occur in four possible different conditions as explained below.

1. Distribution of working load on four rails- The maximum stress calculated for the distribution of load on four rails found to be 0.0967 kg/mm^2.
2. Distribution of working load on three rails- The maximum stress calculated for the distribution of load on three rails found to be 0.1290 kg/mm^2.
3. Distribution of working load on two rails- The maximum stress calculated for the distribution of load on two rails found to be 0.1935 kg/mm^2.
4. Distribution of working load on one rail- The maximum stress calculated for the distribution of load on one rails found to be 0.3870 kg/mm^2.

From all the possible loading conditions which may occurred, the maximum stresses coming on member i.e. rail in all possible situations is less than the ultimate tensile strength of aluminium material selected for development which indicates that the chosen cross section can carrying load by rail of harvesting platform without failure.

3.7.3.2 Stability

The harvesting platform was provided with two cross aluminium bracings on either sides for the purpose of stability. The thickness of bracing was 3 mm. The bracings could be assembled and disassembled while transportation of harvesting platform from one place to another.

3.7.4 Fruit collecting basket

Fruit collecting basket was used to collect the fruits after harvesting and transportation from field to storage house or further process. A fruit collecting basket made of 8 mm diameter mild steel rod and cover the fruit collecting basket by cloth. It can be fixed to safety guard of harvesting platform by two S shape hooks while harvesting fruits located on top portion of the tree by using harvesting platform. The fruit collecting basket was used to collect the fruit harvested and fruit plucked by hand from the ground surface. The dimensions of fruit collecting basket presented in Table 3.2. The detailed view of fruit collecting basket is shown in Fig 3.14. During development of fruit collecting basket, the capacity of fruit collecting basket was decided as per the safe load carrying capacity by ruck sack method of the operator with relative heart rate is about 109 (Murrell, 1963) and also considered the bulk density of matured Nutmeg fruit.

Table 3.2 Dimensions of fruit collecting basket

Sr. No.	Particular	Dimensions
1.	Diameter of fruit collecting basket, mm	250
2.	Depth of fruit collecting basket, mm	400
3.	Volume of fruit collecting basket, liter	19.63
5.	Capacity of fruit collecting basket on weight basis, kg	11
6.	Material of fruit collecting basket	Cotton cloth
7.	Width of belt of fruit collecting basket, mm	35
8.	Material of belt	Nylon
9.	Weight of empty collection basket, kg	0.5

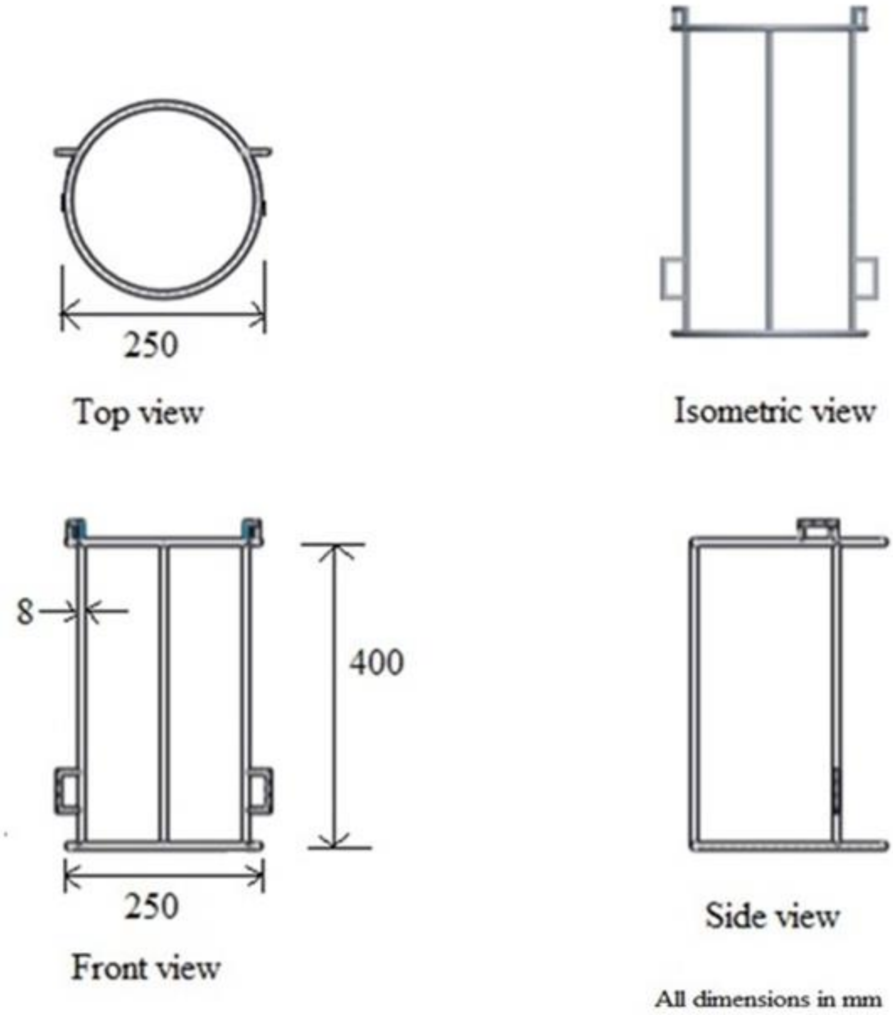


Fig 3.14 Developed fruit collecting backset

3.8 Nutmeg harvesting methods

Three Nutmeg harvesting methods were considered viz., (i) Beating of fruits by bamboo stick (ii) Hook Method (iii) Newly developed manual Nutmeg harvesting system. The details of above listed Nutmeg harvesting methods are presented below.

3.8.1 Beating of fruits by bamboo stick

Beating of Nutmeg fruits by bamboo stick is most commonly used method for harvesting Nutmeg. The Nutmeg fruits are harvested by striking of fruit by bamboo stick (sometimes ladder is used) Plate 3.12. The matured fruits were selected and beat by stick one by one. On striker, the fruit get detached from plant and fall on the ground. The fruit fallen on ground is collected. Beating of Nutmeg fruits by bamboo stick is very time consuming as well as risky and drudgerius. In this method, two people are required one for Nutmeg fruit beating and other for collection and transport the harvested Nutmeg fruits from field to storage house or further process.

Plate 3.12 Beating of Nutmeg fruits by bamboo stick

3.8.2 Hook method

In traditional method of Nutmeg harvesting are generally done by either hand picking of fruits situated upto hand reach height or bamboo stick with hook at its extreme end known as hook used for harvesting fruits located in upper periphery of the plant. A bamboo stick of 30 to 40 mm diameter and 1.5 to 2 m long is mostly used for fruit harvesting purpose (Plate 3.13). As weight of bamboo is more, the operation is drudgeries and harvested fruit falls on ground. The fruits are the collected in bag and basket.

Plate 3.13 Hook method of Nutmeg harvesting

3.8.3 Newly developed manual Nutmeg harvesting system

Considering the drawbacks of the above two existing methods a manual Nutmeg fruit harvesting system was developed. Single man can operate it. The system consists of fruit harvester, telescopic pole, harvesting platform, and fruit collecting basket. The operator locate the matured fruits in V-shaped picker hook and fruit was gently pulled with little force and collect the harvested fruits in collecting net then to fruit collecting basket. The harvested fruits are transported from field to storage house or further process. The operator can increase or decrease the length of telescopic pole as per requirement.

Newly developed harvesting system is used to harvest matured Nutmeg fruit manually. In this method, fruits can be harvested by three different ways as per the requirement. The first one is to harvest the fruit from ground surface by hand picking upto operator reach. The second way is to use fruit harvester with telescopic pole upto 4 m height from operator shoulder. The height of telescopic pole can be increased or decreased as per the operators requirement (plate 3.14). Third way is use of harvesting platform and harvester with telescopic pole to harvest the fruit located on top portion of the tree or upto height 8.2 m from ground level. The detailed view of Newly developed harvesting system as shown in plate 3.16. After harvesting, collect the overall harvested fruits in fruit collecting basket and transported from field to store house or further process by using fruit collecting basket. Only matured fruit are harvested. The fruit does not fall and hence damage to fruit is minimized. The pericarp of such harvested fruit can be used for further processing, which otherwise might be waste.

The above mentioned three different harvesting systems viz., Beating of fruits by bamboo stick, hook method and Newly developed harvesting manual Nutmeg harvesting system were analyzed the field performance in terms harvesting capacity, damage fruit per cent, harvesting time, labour requirement and harvesting cost. The field performance above three harvesting method was evaluated as per the standard procedure given below in section 3.9.

Plate 3.14 Developed manual Nutmeg harvesting system without harvesting platform

Plate 3.15 Nutmeg plucking by hand with developed fruit collecting basket upto operator reach

Plate 3.16 View of newly developed manual Nutmeg harvesting system

3.9 Performance evaluation of newly developed manual Nutmeg harvesting system

3.9.1 Field test

To evaluate the field performance of developed Nutmeg harvesting system, test were carried out at the Department of Horticulture farm, DR.BSKKV., Dapoli, and farmers field Murdi, Anjarle, Kelasi villages of Dapoli tahasil Dist- Ratnagiri. Six male subjects were selected for performance evaluation of developed manual Nutmeg harvesting system and ergonomic evaluation according to Gite and Singh (1997). The details of the selected subjects are presented in Appendix D. To determine harvesting capacity (kg/h), damage fruit per cent (%), total harvesting time (h), labour requirement, ergonomic evaluation and economics of developed manual Nutmeg harvesting system were determined as per procedure given below. The following observations were taken during field performance of developed manual Nutmeg harvesting system.

3.9.1.1 Harvesting capacity

Harvesting capacity of developed manual nutmeg harvesting system includes sum of all the fruits harvested with and/or without harvesting platform from ground level with in time. Harvesting capacity was estimated by number or weight of harvested fruits per unit time by using following formula given by Hammam *et. al.,* (2011-a).

Harvesting Capacity (Nos./h)) = (Total No. of fruits harvestedÀTime).… (3.7)

And similarly in terms of weight,

Harvesting Capacity (kg/h) = (Weight of harvested fruitsÀTime) .... (3.8)

3.9.1.2 Damage fruit per cent

It includes the number of fruits that got damaged due to scratching or by falling down from the tree during harvesting with harvesting platform or without harvesting platform operation. The following formula is used to calculate the damage per cent of fruit is given by Hammam *et. al.,* (2011-a).

Mathematically it was calculated as,

Damage fruit per cent = (No. of fruits damaged during harvestingÀTotal no. of fruits harvested) x 100... (3.9)

3.9.1.3 Total harvesting time

The total harvesting time that required to locate/positioned and detaching the mature fruits by fruit harvester, and collecting them in the fruit collecting basket was measured and recorded. The total harvesting time includes the lost time for moving tool and harvesting ladder between Nutmeg trees and branches and the time required to empty net and fill into fruit collecting basket.

3.9.1.4 Labour requirement

The labour requirement for picking or harvesting the fruits from the tree, to empty the fully loaded net into the collecting basket and to transport the filled basket to the storehouse or further process was recorded.

3.9.2 Performance evaluation of traditional Nutmeg harvesting method

The performance of traditional Nutmeg harvesting system, evaluated on basis of following parameters viz., harvesting capacity (kg/h), damage fruit per cent (%), total harvesting time (h), labour requirement, economics.

3.9.2.1 Harvesting capacity

Harvesting capacity of traditional harvesting method includes sum of all the fruits harvested fruit by bamboo stick or hook method. It was estimated by number or weight of harvested fruits per unit time by using following formula given by Hammam *et al.,* (2011).

Harvesting Capacity (Nos./h)) = (Total No. of fruits harvestedÀTime) … (3.10)

And similarly in terms of weight,

Harvesting Capacity (kg/h) = (Weight of harvested fruitsÀTime) ... (3.11)

3.9.2.2 Damage fruit per cent

It includes the number of fruits that got damaged due to beating, scratching. The following formula is used to calculate the damage per cent of fruit is given by Hammam *et. al.,* (2011-a).

Mathematically it was calculated as,

Damage fruit per cent = (No. of fruits damaged during harvestingÀTotal No. of fruits harvested) x 100... (3.12)

3.9.2.3 Total harvesting time

It includes the harvesting time by bamboo stick or hook and collecting the fruits after harvesting from the ground surface.

3.9.2.4 Labour requirement

The labour requirement for harvesting the fruit, collecting of fruit from ground surface and transport the harvested fruit from field to the storehouse or further process was recorded.

3.9.2.5 Cost economics

Cost economics of traditional Nutmeg harvesting method was calculated as per the procedure given in 3.9.4 on hour basis or kg basis.

3.9.3 Ergonomic evaluation of developed manual Nutmeg harvesting system

The developed manual Nutmeg harvesting system was evaluated ergonomically to determine the energy expenditure rate (EER), overall discomfort rating (ODR), body parts discomfort score (BPDS), acceptable work load (AWL) and limit of continuous performance (LCP) of subjects. Six male subjects in age group of 20 to 25 yrs perform the harvesting operation and observations were recorded.

3.9.3.1 Calibration of subjects

Calibration of subject means to develop the relationship between physiological parameters like heart rate (HR) and oxygen consumption rate (OCR). The developed relationship between heart rate (HR) and oxygen consumption (OCR) could be used to predict the OCR for the particular value of HR while during the field operation. Using the measured parameter oxygen consumption (OCR), energy expenditure rate (EER) was calculated using the calorific value of oxygen (20.88 kJ/lit).

3.9.3.2 Subject selection

Selection of subjects plays an important role in conducting the ergonomic investigations. According to Gite and Singh (1997) Maximum oxygen uptake, heart rate and muscle strength decreases significantly with old age. The maximum strength/ power can be expected from the age group of 25 to 35 years. Similarly, Grandjean (1982) reported that the maximum percentage of work could be expected during 20 to 30 years considering this a healthy age group ranging 20-35 years free from respiratory or any other health problem. Therefore, the subjects were selected within this age group (20 to 35 years). Six male agricultural subjects of the age group (20 to 35 years) were randomly selecting for the study. The details of selected subjects are presented in Appendix IV.

3.9.3.3 Instruments used for calibration of subject

Computerized treadmill (COSMED S.r.I) was used as loading device whereas computerized energy measurement system (K5b2) was used for measurement of heart rate and oxygen consumption of the subject.

3.9.3.3.1 Tread mill

Tread mill ergometer is a test machine which has an adjustable elevation and speed can be read in per cent and kmph. The tread mill ergometer is equipped with computer showing elevation (%), speed (kmph), heart rate (bpm), total calibration time (second) and this time averaged into minute, total covered distance in km or meter, VO2 max (mL/min). The elevation of the tread mill should be adjusted as test protocol so that, when subject walk comfortably in the middle of the running belt. The adjustment of the accessories should be proper to comfortable ride. The computer controller for the tread mill ergometer can perform protocols in addition to manual operation. The detailed specifications of tread mill ergometer are presented at Appendix V and computerized treadmill ergometer (COSMED S.r.I) is shown in plate 3.17.

Plate 3.17 COSMED S.r.I tread mill used for ergonomic evaluation

3.9.3.3.2 Computerized energy measurement system (K5b2)

Physiological parameters viz., heart rate and oxygen consumption were noted by energy measurement system (K5b2) shown at plate 3.18.It can be used in laboratory. The detailed specifications of energy measurement system (K5b2) are presented in Appendix V.

Plate 3.18 Computerized energy measurement system (K5b2)

3.9.3.4 Calibration process

Before start of calibration of subject, the warming up of energy measurement system (K5b2) was done. Different calibrations of K5b2 such as room air, turbine, delay and reference gas were also done before its actual use for measuring oxygen consumption rate. The standard procedures, sequences and intervals were followed for all those calibrations. The calibration process was carried out during the year 2017-2018. After instrument calibrations, it was made ready for use. The calibrations of six male subjects were undertaken. The subjects were asked to report in the laboratory 30 min before the actual calibration. It was ensured that they had good sleep in previous night. It was also ensured that they were free from the influence of stimulants such as alcoholic, drinks, cigarettes etc. and has no cardiac disease.

Calibration of subjects were carried to determine the aerobic capacity of subjects and the aerobic capacity was measured through conducting sub maximal tests on computerized tread mill (COSMED S.r.I). The subject was asked to walk on the tread mill at prescribed protocol which is set by manual. The tread mill elevation and speed is maintained by computer as per test protocol. The elevation and speed was automatically increased at an interval of 2 min through computer software. The heart rate and VO2 values are directly downloaded to the computer breadth by breadth. Those values are averaged for one minute duration to get the correlation of heart rate and oxygen consumption rate.

A target heart rate was taken as approximately 75 % of the age predicted maximum heart rate. The maximum heart rate attainable by the subject was computed by the following relationship.

$$HR\ (max) = 220 - \text{age in years} \qquad ...(3.13)$$

Correlation between heart rate and oxygen consumption rate at specified sub maximal workloads were developed and the regression line was extrapolated to the age predicted maximum heart rate and VO2 max corresponding to HR max was noted.

Plate 3.19 Subject calibration by using computerized treadmill (COSMED S.r.I)

3.9.3.4.1 Maximum aerobic capacity (VO2 max)

The maximum aerobic capacity also called as VO2 max or maximum oxygen uptake capacity was conceived as an international reference standard of cardio-respiratory fitness (Gite and Singh, 1997). The maximum oxygen uptake was the highest oxygen uptake attainable in the subject where a further increase in workload will not result in an increase in oxygen uptake. The acceptable workload (AWL) for Indian workers was the work consuming 35 per cent of VO2 max (Saha *et. al.*, 1979). To ascertain whether the operation of the selected implement is within the acceptable workload (AWL), it is necessary to compute the VO2 max for each subject. Because of the risk that is involved in testing a person on a maximal task, various sub maximal tests have been advocated. The intersection of the computed maximum heart rate of the subjects with the plotted calibration chart line of fit to the oxygen uptakes defines the maximum aerobic capacity (VO2 max) of the individual. The VO2 max for all the subjects were computed and recorded.

3.9.3.4.2 Assessment of physiological cost

The experiment was conducted in Nutmeg field of Dept. of Horticulture, College of Agriculture, DBSKKV., Dapoli during year 2017-2018. The information about experiment was given to subjects so as to ensure their full co-operation. Heart rate monitor (Polar, RS 400^{Tm}) was used for recording heart rate values in bpm. Each subject was given 30 minutes rest before starting of harvesting operation. Each trial was started taking 10 min resting heart rate data of the subject. The average resting heart rate was computed and recorded for each subject. After resting each subject was asked to perform harvesting operation for 15 minutes, during that period heart rate values were recorded. The recorded heart rate values were downloaded to the computer. The average heart rate from 6^{th} to 15^{th} minutes of operation was used as working heart rate for the further calculation and analysis. The same procedure was used to all the selected subjects.

The ergonomic evaluation was carried out with the following parameters.

1. Heart rate (HR)
2. Oxygen consumption rate (OCR)
3. Energy Expenditure rate (EER)
4. Acceptable work load (AWL)
5. Limit of continuous performance (LCP)
6. Overall discomfort rating (ODR)
7. Body part discomfort score (BPDS)

3.9.3.4.2.1 Heart rate

Physiological methods can be applied to evaluate the physical demands of any work in terms of energy expenditure. Basically, any increase in heart rate and oxygen uptake over and above that required basal metabolism can be used as index of the physiological cost to an individual of performing work. Heart rate as a primary indicator of circulatory function and oxygen consumption representing the metabolic conversion taking place in the body has a linear and reliable relationship. Heart rate measurements have a major advantage over oxygen consumption as an indicator of metabolic process. Heart rate responds more quickly to changes in work demands and hence indicates more readily quick changes in body function due to changes in work requirement (Kroemer *et al*., 1997). During operation of selected machine, only heart rate of the subject performing the task was recorded with the help of computerized heart rate monitor and noted the readings.

3.9.3.4.2.1.1 Heart rate monitor

The heart rate was measured using Polar RS 400^{Tm} heart rate monitor. It is a portable instrument to measure the heart rate. This can be used in the field directly for recording the heart rates of worker. It has following basic parts.

3.9.3.4.2.1.2 Transmitter

Transmitter consists of an electrodes and connector. Transmitter picks up heart rate from the body of the subject and converts to electromagnetic signals with the help of two electrodes, which is fixed in the grooved rectangular area on the underside of the belt transmitter. For better sensing, the electrode areas of the strap are to be well moistened.

3.9.3.4.2.1.3 Elastic strap

Elastic strap is having a connector which is placed is in a central, upright position on the chest of the subjects. The strap length is adjusted in such way that it fit snugly and comfortably around the chest, just below the chest muscles of the subjects.

3.9.3.4.2.1.4 Receiver

Receiver is the unit which receives the signal from the transmitter, displays it on the screen and records the data in the memory. The receiver has provision to operate heart rate monitor. It shows the maximum heart rate, minimum heart rate and average heart rate. It can be programmed by polar pro trainer software. The receiver unit must be placed within one meter range and it can be either in watchstrap.

3.9.3.4.2.1.5 Interface

This is the unit, which transmits the recorded heart rate values to the computer. Recorded heart rate values of the subjects are transmitted to the computer, which are also displayed in graphical form. The values of maximum, minimum and average heart rate of the subjects during the operation are also presented. The average value of heart rate (HR) per min recorded in bpm. The specifications of the computerized heart rate monitor are presented in Appendix V.

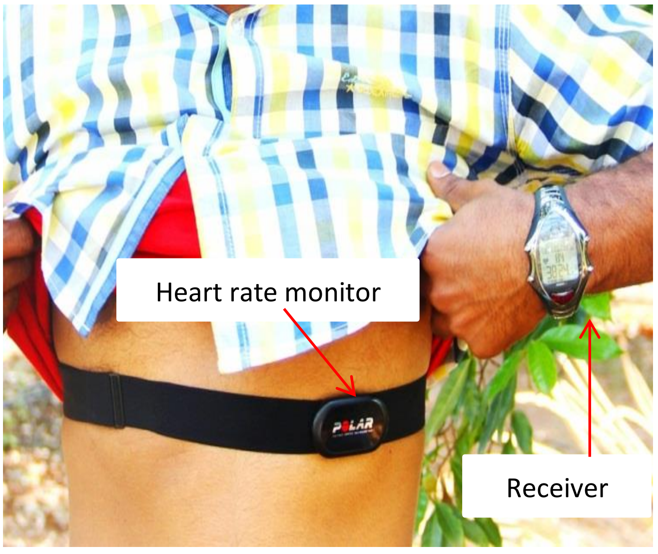


Plate 3.20 Computerized heart rate monitor (Polar RS 400^{Tm})

3.9.3.4.2 Oxygen Consumption Rate (OCR)

The oxygen consumption of subjects during the operation was carried by indirect assessment. The subjects were calibrated by the process as explained in section 3.9.2.6. Each subject's calibration chart was plotted and that showed oxygen consumption values corresponding to the average working heart rate. Oxygen consumptions of all subjects while operating developed manual Nutmeg harvester were predicted from calibration chart of each individual subject.

3.9.3.4.3 Energy Expenditure Rate (EER)

From the values of heart rate (HR) observed during the trials, the corresponding values of oxygen consumption rate (OCR) of the subjects during operation with developed manual Nutmeg harvester were predicted from the calibration chart of each individual subjects. The energy expenditure rate (EER) for male subjects was determined by using the following relation for male subjects.

Energy expenditure rate (kJ/min) = 20.88 x OCR ……………… (3.14)

The values of heart rate (HR), oxygen consumption rate (OCR) and energy expenditure rate (EER) for all the subjects were averaged to get the mean values for all the selected subjects.

3.9.3.4.4 Acceptable Work Load (AWL)

Physiological parameters of subjects increase as the workload increases. Physiological parameters depend upon the workload, and the maximum values, which could be attained in normal healthy individuals, will be up to VO2 max however at this extreme workload, a person can work only for a few seconds. The acceptable workload (AWL) for Indian workers was the work consuming 35 per cent of the VO2 max (Saha *et al.*, 1979). To ascertain whether the operation of the developed manual Nutmeg harvester was within the acceptable workload (AWL), the percent of VO2 max for each subject was calculated.

3.9.3.4.5 Limit of Continuous Performance (LCP)

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 from rest to maximal work.

To have a meaningful comparison of physiological response, Δ values (Increase over resting values) for heart rate (work pulse) were calculated. For this, the average values of the heart rate at rest level and at working condition were used. The values of physiological responses i.e. heart rate (ΔHR) of the selected subjects also known as work pulse were averaged to get the mean value for the entire developed manual Nutmeg harvester. The calculated values of work pulse for each subject were compared with the acceptable work pulse values of 40 bpm.

3.9.3.4.6 Subjective discomfort rating

Discomfort is the body pain arising because of the working posture and for an excessive stress on muscles due to the effort involved in the activities. It is also called overall discomfort. Drudgery caused due to bad posture is reflected in terms of postural discomfort experienced by the worker. It has been observed by Gite and Singh (1997) that muscular discomfort of body is comparatively more important than HR and OCR in agricultural operations as limiting factors. For assessment of body discomfort, various subjective rating scales have been developed, but the methods which are commonly followed are Borg (1985), Corlet and Bishop (1976) and Visual Analog Discomfort (VAD). In the present study two methods, i.e. Overall Discomfort Rating (ODR) and Body Part Discomfort Score (BPDS) were selected to assess the body discomfort.

The subjective rating scale viz., overall discomfort rating (ODR) and scale Body Part Discomfort Score (BPDS) were used to assess the discomfort subjectively as follows.

3.9.3.4.6.1 Overall Discomfort Rating (ODR)

Overall discomfort rating is the method used to assess the overall body discomfort. For the assessment of overall discomfort rating a 10 point psychophysical rating scale (0 - no discomfort, 10 extreme discomforts) was used. A scale of 70 cm length was fabricated having 0 to 10 digits marked on it equidistantly. A movable pointer was provided to indicate their overall discomfort rating on the scale. It is shown in plate 3.21.The overall discomfort ratings given by each subjects are added averaged to get the mean rating.

After 20 min operation with developed manual Nutmeg harvester, each subject was asked to indicate the overall discomfort level on the 10 point rating scale. The values were tabulated and averaged.

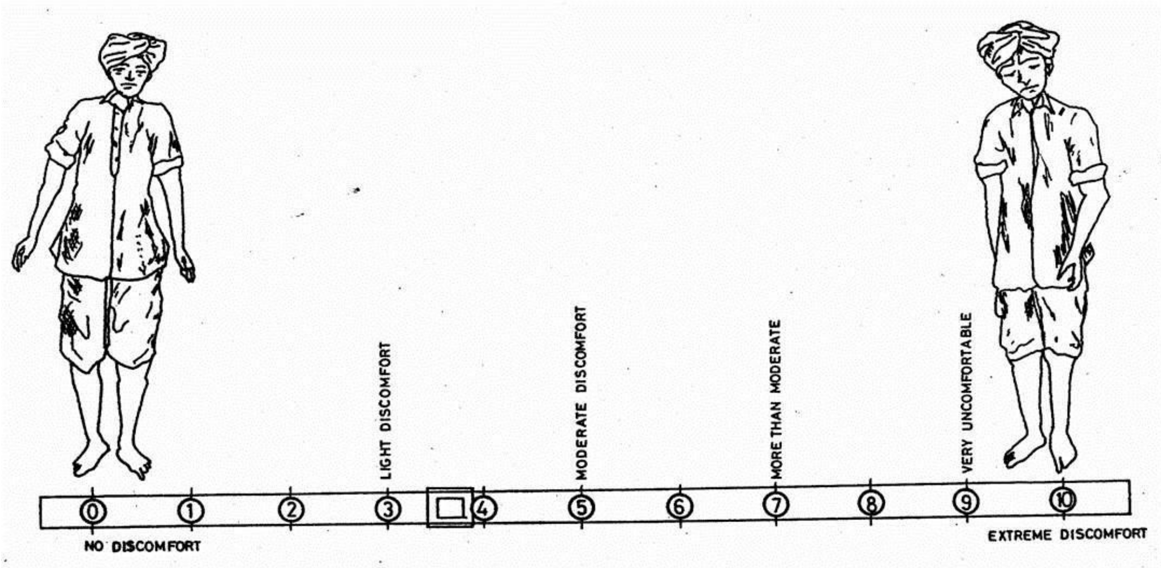


Plate 3.21 Overall discomfort rating scale

3.9.3.4.6.2 Body Part Discomfort Score (BPDS)

The subject's body is divided into 27 regions. The body chart (Plate 3.22) was shown to the subject after finishing trial with developed manual Nutmeg harvester. Each 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 subject was asked to fix the pin on the body part in the order of one pin for maximum pain, two pins for next maximum pain and so on. The number of different groups of body parts which were identified from extreme discomfort to no discomfort represented the number of intensity levels of pain experienced. The body part discomfort score of each subject was calculated by multiplying by the number of body parts corresponding to each category. The total body part score for a subject would be the sum of all individual scores of the body parts assigned by the subject. The body discomfort score of all the subjects was added and averaged to get mean score.

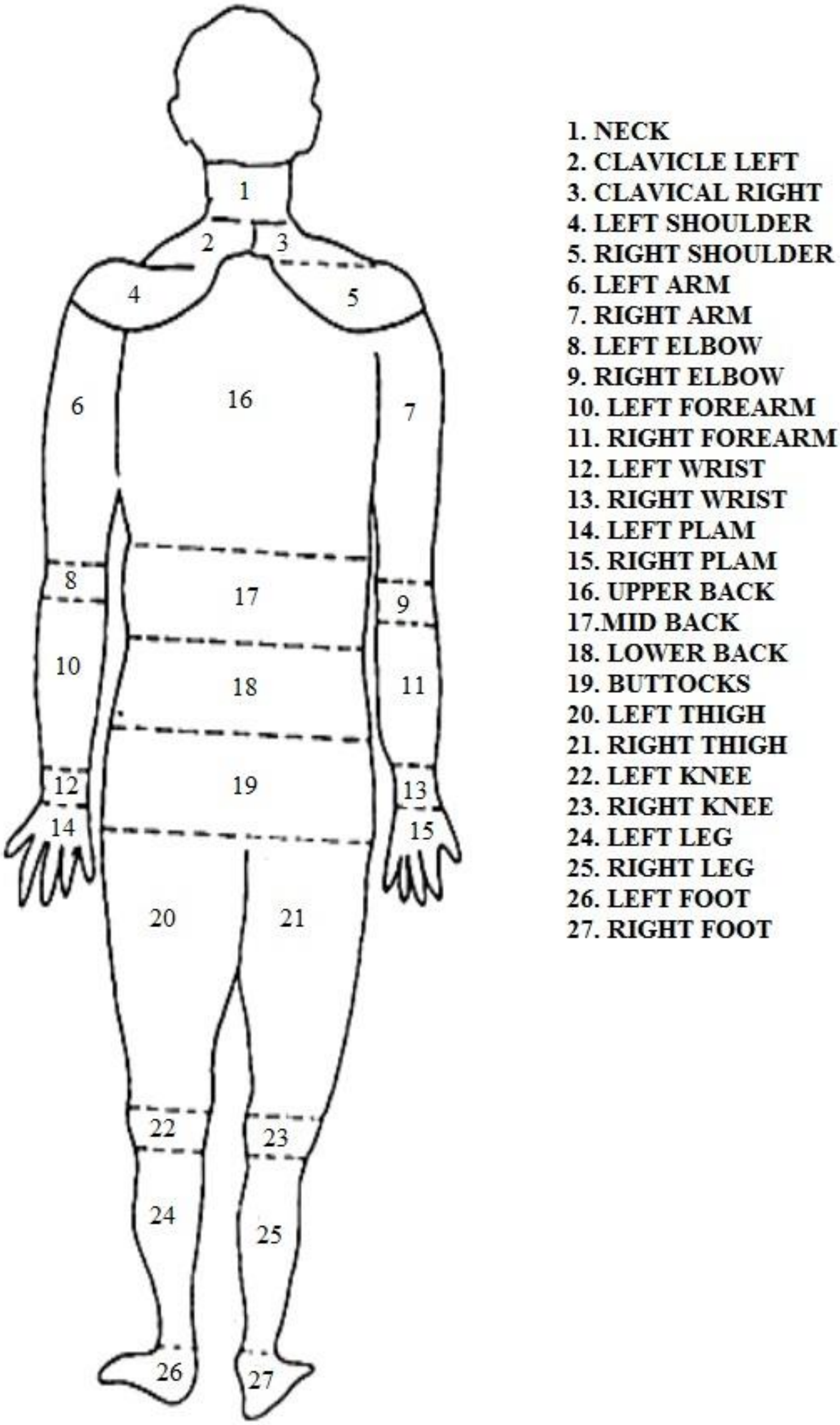


Plate 3.22 Body part discomfort score chart

3.9.4 Estimation of cost of operation of developed manual Nutmeg harvesting system

The operating cost of developed manual nutmeg harvesting system includes fixed cost and variable cost. The life of developed manual nutmeg harvesting system and its use per year is considered as 5 years and 240 h/yr (4 x 30 x 2= 240) respectively.

3.9.4.1 Fixed cost

1. Depreciation, Rs/h = (C-S)/(L×H)
2. Interest @ 5 %, Rs/h = [(C+S)/2]×[i/(100×H)]

Where,

C = Initial cost or cost of machine, Rs

H = Annual use of machine, hrs

i = Interest rate, %

L = Total life of machine, yrs

S = Salvage value, (10 % of initial cost)

3. Housing, Rs/h = 1.5 % of Initial cost
4. Total fixed cost = 1 + 2 + 3

3.9.4.2 Variable cost

1. Operators cost, Rs/h = Wages of operator / Working hours
2. Repair and maintenance, Rs/h = 10 % of Initial cost
3. Total variable cost = 1 + 2

3.9.4.3 Operating cost

Operating cost = Fixed cost + Variable cost

The detailed cost economics is presented at Appendix VI.

3.10 Comparative performance of newly developed Nutmeg harvesting system with traditional harvesting method

The comparative performance of newly developed manual Nutmeg harvesting system with traditional harvesting method in terms of harvesting capacity (kg/h), damage fruit per cent, total harvesting time (h), labour requirement and cost economics as presented in 3.9.1, 3.9.2and 3.9.4. The results were analyzed with standard procedure.

CHAPTER IV

RESULT AND DISCUSSION

This chapter presents the analysis and interpretation of experimental results of all the phases of the study. It includes the physical and engineering properties of matured nutmeg fruits, fruit detachment force and FDF weight ratio of matured and unmatured fruits, the field performance of the developed manual Nutmeg harvesting system, ergonomic evaluation in terms of physiological cost of the operator's energy expenditure rate (EER), body part discomfort scores (BPDS) and overall discomfort ratings (ODR) experienced by the subjects and economics of developed manual Nutmeg harvesting system. The performance of newly developed Nutmeg harvesting system was also compared with two traditional method of Nutmeg harvesting.

4.1 Nutmeg plant characteristics

The required plant characteristics of Nutmeg tree were determined to develop a manual nutmeg harvesting system. The measurement of plant characteristics as per the procedure given in 3.1.Nutmeg plant characteristics include tree height, bark height, distance between plant to plant and row to row distance, and fruit distribution pattern of Nutmeg (Cv Konkan Vishwashri) tree. Nutmeg plant characteristics were determined by selecting 30 numbers of trees. The height of Nutmeg tree was found in the range from 7.3 to 11.2 m and bark height was 1.2 to 1.78 m from ground level. The inside, outside, and top of fruit percentage by number basis was found in the ranges 18 to 29 %, 60 to 69 % and 4 to 20 %.

It is observed in Nutmeg plant approximately 70 per cent fruits are located between 2.5 to 7 m from ground and outside surface of the plant similarly,20 per cent fruits located upto 2.5 m height from ground and inside the plant canopy. Average height of the plant was found 9.2 m. The above mentioned Nutmeg plant characteristics was considered for design of newly developed harvesting system in terms of height of harvesting platform, length of telescopic pole, shape and strength of fruit harvester and capacity of fruit collection net.

4.2 Physical properties of matured nutmeg fruit

The required physical properties of matured Nutmeg fruits were determined as per procedure given in 3.2. The observed physical properties of length, width, thickness and weight of nut, mace and pericarp of matured nutmeg fruit of three Nutmeg varieties are presented in the Appendix II. The minimum, maximum and average values of the physical properties of matured nutmeg fruits are shown in the

Table 4.1, 4.2 and 4.3 for three different varieties namely Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively. The following physical and engineering properties of Nutmeg fruit was considered for designing the fruit harvester, capacity of fruit collection net as well as capacity of fruit collecting basket.

4.2.1 Fruit length

The length of matured fruit was measured as per the procedure given in 3.2.1. The length of matured Nutmeg fruit was determined by taking each 50 numbers of Nutmeg fruits of three different varieties of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri. The length of matured Nutmeg fruits varied in the range from 52.62 to 79.01 mm, 43.56 to 74.73 mm, and 43.73 to 78.11 mm for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively. An average fruit length of single fruits was obtained 65.94 (±7.28), 57.21 (±7.92) and 60.31 (±8.99) mm respectively.

It is observed that, length of Konkan Sughandha fruit was higher as compared to other variety of Nutmeg fruits and lower in Konkan Shrimanti as compared to other variety. For designing the V shaped picker hook of fruit harvester, the above values of fruit length was considered.

4.2.2 Fruit breadth

The breadth of matured fruit was measured as per the procedure given in 3.2.2. The breadth of matured Nutmeg fruit was determined by taking each 50 numbers of Nutmeg fruits of three different varieties of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri. The breadth of matured Nutmeg fruits varied in the range from 44.34 to 65.2 mm, 38.71 to 63.28 mm, and 34.26 to 60.18 mm for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively. An average fruit breadth of single fruits was obtained 54.41 (±4.74), 50.14 (±6.18), and 45.11 (±6.15) mm respectively.

It is observed that, breadth of Konkan Sughandha fruit was higher as compared to other variety of Nutmeg fruits and lower in Konkan Vishwashri as compared to other variety. For designing the V shaped picker hook of fruit harvester, the above values of fruit breadth was considered.

4.2.3 Fruit thickness

The thickness of matured Nutmeg fruit was measured as per the procedure given in 3.2.3. The thickness of matured Nutmeg fruit was determined by taking each 50 numbers of matured Nutmeg fruits of three different varieties of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri. The thickness of matured Nutmeg fruits varied in the range from 39.11to 54.32 mm, 33.8 to 68.69 mm, and 29.95 to 71.4 mm for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively. An average fruit thickness of single fruits was obtained 46.07 (±3.71), 43.43 (±6.83), and 38.61 (±6.90) mm respectively.

It is observed that, thickness of Konkan Sughandha fruit was higher as compared to other variety of Nutmeg fruits and lower in Konkan Vishwashri as compared to other variety. For designing the V shaped picker hook of fruit harvester, the above values of fruit thickness was considered.

4.2.4 Weight of fruit

The weight of matured Nutmeg fruit was determined as per the procedure given in 3.2.4. The weight of matured fruit was weighed by taking each 50 numbers of Nutmeg fruits of three different varieties of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri. The weight of matured Nutmeg fruits varied in the range from 46.01 to 106.6, 30.2 to 102.9 and 27.1 to 86.2 g for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively at moisture content 39.53 %. An average fresh fruit weight of single fruits was observed 74.83 (±15.03), 57.9 (±21.09) and 43.72 (±16.01) g respectively.

It is observed that, weight of Konkan Sughandha fruit was maximum as compared to other variety of Nutmeg fruits and minimum in Konkan Vishwashri as compared to other variety. For designing the fruit harvester size and capacity fruit collection net, the above values of weight of fruit was considered.

4.2.5 Weight of nut

The weight of Nut was determined as per the procedure given in 3.2.5. The weight of Nut was weighed by taking each 50 numbers of Nutmeg fruits of three different varieties of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri. The weight of Nut varied in the range from 5.6 to 15, 2.1 to 21.4 and 2.7 to 11.2 g for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively at 33.33 % moisture content. An average Nut weight of single Nut was observed 10.16 (±2.34), 8.36 (±3.80) and 5.95 (±0.95) g respectively.

It is observed that, Nut weight of Konkan Sughandha fruit was maximum as compared to other variety of Nutmeg fruits and minimum in Konkan Vishwashri as compared to other variety.

4.2.6 Weight of mace

The weight of Mace was determined as per the procedure given in 3.2.6. The weight of Mace was weighed by taking each 50 numbers of Nutmeg fruits of three different varieties of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri. The weight of Mace varied in the range from 1.4 to 6.2, 0.7 to 5.8 and 0.8 to 4.6 g for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively at 43.33 % moisture content. An average Mace weight of single Mace was observed 3.35 (±0.99), 2.9 (±1.23) and 2.39 (±2.29) g respectively.

It is observed that, Mace weight of Konkan Sughandha fruit was maximum as compared to other variety of Nutmeg fruits and minimum in Konkan Vishwashri as compared to other variety.

4.2.7 Weight of pericarp

The weight of pericarp was determined as per the procedure given in 3.2.7. The weight of pericarp was determined by taking each 50 numbers of Nutmeg fruits of three different varieties of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri. The weight of fresh pericarp varied in the range from 34.38 to 88.8, 26.3 to 86.5 and 16.3 to 70.9 g for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively at 44.11 % moisture content. An average pericarp weight of single pericarp was observed 61.31 (±12.90), 46.6 (±17.44) and 37.08 (±15.52) g respectively. It was observed that, pericarp weight of Konkan Sughandha fruit was maximum as compared to other variety of Nutmeg fruits and minimum in Konkan Vishwashri as compared to other variety.

For design and development of manual Nutmeg harvesting system, the above all the values was considered viz., fruit length, fruit breadth, fruit thickness and weight of fruit, weight of nut, weight of mace, and weight of pericarp.

4.3 Engineering properties of Nutmeg fruit

The required engineering properties of matured Nutmeg fruits were determined to develop a manual Nutmeg harvesting system as per procedure given in 3.3. The measured of engineering properties of size or equivalent diameter, sphericity, unit volume, projected area, surface area of matured nutmeg fruits are presented in Appendix II. The minimum, maximum and average values of the engineering properties of matured nutmeg fruits are shown in the Table 4.1, 4.2 and 4.3 for three different verities namely Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively. The engineering properties of Nutmeg fruit was considered for designing the fruit harvester, capacity of fruit collection net as well as fruit collecting basket as presented below.

4.3.1 Size or equivalent diameter

The size or equivalent diameter of nutmeg fruit was determined as per the procedure given in 3.3.1. The size or equivalent diameter is the geometric mean of the three dimensions viz., length, breadth, thickness. The size of a fruit of irregular shape can be determined by equivalent diameter (ED). A sample of 50 numbers of fruits was taken to calculate equivalent diameter (ED) of three different variety of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively. An average equivalent diameter of matured Nutmeg fruit was found as 54.88, 49.94, and 47.18 mm for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri varieties of Nutmeg fruit respectively.

It was observed that, equivalent diameter of Konkan Sughandha fruit was maximum as compared to other variety of Nutmeg fruits and minimum in Konkan Vishwashri as compared to other variety. For designing fruit harvester and selection of fruit collection net, the above properties were considered.

4.3.2 Sphericity

The sphericity was determined to define the shape of matured Nutmeg fruits. The sphericity of matured fruit was determined as per the procedure given in 3.3.2. A sample of 50 fruits was taken to calculate the sphericity of the matured fruit of three different variety of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively. The average sphericity was found as 0.83, 0.87 and 0.78 for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri varieties of Nutmeg fruit respectively.

It was observed that, sphericity of Konkan Shrimanti fruit was maximum as compared to other variety of Nutmeg fruits and minimum in Konkan Vishwashri as compared to other variety. For designing fruit harvester, selection of fruit collection net and shape of the V shaped picker hook, the above properties were considered.

4.3.3 Unit volume

The unit volume of fruits was determined from the values of L, B and T as per the procedure given in 3.3.3. A sample of 50 fruits was taken to calculate the unit volume of the matured fruit of three different variety of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively. The average unit volume was found as 86.57, 65.25 and 55.01 cm^3 for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri varieties of Nutmeg fruit respectively.

It was observed that, unit volume of Konkan Sughandha fruit was maximum as compared to other variety of Nutmeg fruits and minimum in Konkan Vishwashri as compared to other variety. For designing fruit harvester, selection of fruit collection net and volume of the fruit collecting basket, the above properties were considered.

4.3.4 Projected area

The projected area of nutmeg fruit was calculated as per the procedure given in 3.3.4. A sample of 50 fruits was taken to calculate the unit volume of the matured fruit of three different variety of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri respectively. The average projected area were found as 23.67, 19.61and 17.50 cm^2 for Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri varieties of Nutmeg fruit respectively.

It was observed that, projected area of Konkan Sughandha fruit was maximum as compared to other variety of Nutmeg fruits and minimum in Konkan Vishwashri as compared to other variety. For designing fruit harvester, selection of fruit collection net and volume of the fruit collecting basket, the above values were considered.

4.3.5 Surface area

The surface area of Nutmeg fruit was calculated as per the procedure given in 3.3.5. A sample of 50 fruits were taken to calculate the surface area of the matured fruit of three different variety of Nutmeg fruit viz., Konkan Sughandha, Konkan Shrimanti and Konkan Vishwashri which had average surface area as 94.63, 78.37 and 69.94 cm^2 respectively.

It was observed that, surface area of Konkan Sughandha fruit was maximum as compared to other variety of Nutmeg fruits and minimum in Konkan Vishwashri as compared to other variety. For designing fruit harvester, selection of fruit collection net and volume of the fruit collecting basket, the above values were considered.

4.3.6 Bulk density

The bulk density of matured Nutmeg fruit was calculated as per the procedure given in 3.3.6. A sample was taken to calculate the bulk density of matured Nutmeg fruit of Konkan Vishwashri variety. The average bulk density was found 0.58 g/cm^3.

The above mentioned bulk density of matured fruit was used to design of capacity of fruit collecting basket and fruit collection net of fruit harvester.

Table 4.1 Physical and Engineering properties of Nutmeg fruits Cv-Konkan Sughandha (Average of 50 fruits)

Sr. No.	Parameters	Min.	Max.	Average
1.	Length, mm	52.62	79.01	65.94
2.	Width, mm	44.34	65.2	54.41
3.	Thickness, mm	39.11	54.32	46.07

4.	Weight of Fruit, g	46.01	106.6	74.83
5.	Weight of Mace, g	1.4	6.2	3.35
6.	Weight of Nut, g	5.6	15	10.16
7.	Weight of Mace+Nut, g	7.8	19.7	13.51
8.	Weight of pericarp, g	34.38	88.8	61.319
9.	Size or Equivalent diameter, mm	45.020	65.40	54.88
10.	Sphericity	0.85	0.82	0.83
11.	Unit volume, cm^3	47.77	146.52	86.57
12.	Projected area, cm^2	15.93	33.62	23.67
13.	Surface area, cm^2	63.67	134.40	94.63
14.	Shape	Elliptical		
15.	Colour	Yellow- Red		

Table 4.2 Physical and Engineering properties of Nutmeg fruits Cv-Konkan Shrimanti (Average of 50 fruits)

Sr. No.	Parameters	Min.	Max.	Average
1.	Length, mm	43.56	74.73	57.21
2.	Width, mm	38.71	63.28	50.14
3.	Thickness, mm	33.8	68.69	43.43
4.	Weight of Fruit, g	30.2	102.9	57.9
5.	Weight of Mace, g	0.7	5.8	2.9
6.	Weight of Nut, g	2.1	21.4	8.36
7.	Weight of Mace+Nut, g	3.4	27.2	11.26
8.	Weight of pericarp, g	26.3	86.5	46.65
9.	Size or Equivalent diameter, mm	38.48	68.74	49.94
10.	Sphericity	0.88	0.91	0.87
11.	Unit volume, cm^3	29.84	170.08	65.25
12.	Projected area, cm^2	11.64	37.14	19.61
13.	Surface area, cm^2	46.52	148.45	78.37
14.	Shape	Elliptical		
15.	Colour	Yellow- Red		

Table 4.3 Physical and Engineering properties of Nutmeg fruits Cv-Konkan Vishwashri (Average of 50 fruits)

Sr. No.	Parameters	Min.	Max.	Average
1.	Length, mm	43.73	78.11	60.30
2.	Width, mm	34.26	60.18	45.11
3.	Thickness, mm	29.95	71.4	38.61
4.	Weight of Fruit, g	27.1	86.2	43.71
5.	Weight of Mace, g	0.8	4.6	2.39
6.	Weight of Nut, g	2.7	11.2	5.95
7.	Weight of Mace+Nut, g	3.9	15.3	8.35
8.	Weight of pericarp, g	16.3	70.9	37.08
9.	Size or Equivalent diameter, mm	35.53	69.62	47.18
10.	Sphericity	0.81	0.89	0.78
11.	Unit volume, cm^3	23.50	175.80	55.01
12.	Projected area, cm^2	9.92	37.96	17.50
13.	Surface area, cm^2	39.66	151.72	69.94
14.	Bulk density, g/cm^3	0.58		
15.	Shape	Elliptical		
16.	Colour	Yellow- Red		

4.4 Fruit detachment force required for Nutmeg fruit

For the purpose of detachment of fruit from the panicle, it was necessary to find out the fruit detachment force. The fruit detachment force (FDF) was measured as per the procedure given in 3.4. During the experimental test, FDF was recorded in kg with the help of load cell (0 to 40 kg). After the load cell calibration, it was attached with the fruit detacher, and further observations were recorded. The changes in FDF/W ratio as a function of maturity time were presented in Table 4.4 and 4.5.

Table 4.4 Fruit Detachment Force (FDF) and FDF/Weight ratio of matured fruit Cv Konkan Vishwashri (Average of 20 fruits)

Parameters	FDF of matured fruit, kg	Weight of matured fruit (W), g	FDF/W ratio, kg/g
Mean	1.39	71.82	0.019
Max. Range	2.35	109.92	0.032
Min. Range	0.65	42.81	0.011
Range	1.7	67.11	0.021
SD	0.404	20.24	0.006
CV, %	29.06	28.18	31.05

Table 4.5 Fruit Detachment Force (FDF) and FDF/Weight ratio of unmatured fruit Cv Konkan Vishwashri (Average of 20 fruits)

Parameters	FDF of unmatured fruit, kg	Weight of unmatured fruit (W), g	FDF/W ratio, kg/g
Mean	1.39	47.45	0.029
Max. Range	1.92	67	0.048
Min. Range	0.97	30	0.020
Range	0.95	37	0.028
SD	0.27	8.51	0.007
CV, %	19.42	17.93	24.78

It was observed that, the ratio was higher for the unmatured fruits and lower for the matured fruits. Higher detachment force was required in unmatured fruit as compared to matured fruit because of its maturity time and stronger bond. Fully matured fruit get easily detached from tree and partially matured fruit require some more detachment force as compared to fully matured fruits. Similarly for unmatured fruit require higher detachment force as compared to fully or partially matured fruit. Weight of the fruit also effect on the detachment force, if weight of fruit is more than the required fruit detachment force will be more as compared to lighter weight of fruit. It was found that average FDF/W ratio for matured and unmatured Nutmeg fruit 0.019 (±0.0059) kg/g and 0.029 kg/g (±0.007) respectively. The details of variation of fruit detachment force/weight for matured and unmatured Nutmeg fruit were presented at Appendix III. The harvester need to be designed for matured fruit and force was used for designing fruit harvesting device.

4.5 Developed manual Nutmeg harvesting system

Newly developed harvesting system used for harvesting of Nutmeg fruit by single person is required to operate the whole harvesting system without any discomfort. It consisted of fruit harvester, telescopic pole, harvesting platform and fruit collecting basket. The detail design method is followed as per 3.6 and 3.7. A view of the newly developed manual Nutmeg harvesting system is shown in Plate 4.1 and detailed dimensions are presented in Table 4.6.

The fruit harvester was connected with telescopic pole by nut bolts. The height of telescopic pole can be increase or decrease as per the requirement within 2 to 4 m range. Fruit harvested up to 4 m height from ground level with fruit harvester and telescopic pole. The remaining fruits are harvested by using harvesting platform and harvester with telescopic pole. Fruit harvested up to 8.2 m from ground level with whole harvesting system without any discomfort. The harvested fruits collected in fruit collecting basket, after harvesting operation this collected fruits transported from field to store house or further process. After harvesting first tree then transport the whole harvesting system to next tree for harvesting matured fruits. The newly developed harvesting system is light in weight, and requires less in repair maintenance.

Plate 4.1 Harvesting of Nutmeg fruit by newly developed manual Nutmeg harvesting system

Table 4.6 Detail of newly developed manual Nutmeg harvesting system

Sr. No.		Particulars	Specifications
I		**Name of the device**	Manual Nutmeg harvesting system
II		**Power source**	Manually operated, by a single person
III		**Fruit harvester**	
	1.	Material of fruit harvester	Mild steel
	2.	Length of V shape picker hook, mm	65
	3.	Width of V shape picker hook, mm	32
	4.	Thickness of V shape picker hook, mm	03
	5.	Angle between V shape picker hook, deg.	35
	6.	Diameter of circular ring, mm	200
	7.	Thickness of circular ring, mm	08
	8.	Length of connector, mm	75

	9.	Diameter of connector, mm	20
	10.	Thickness of connector, mm	03
	11.	Weight of fruit harvester with fruit net, g	530
IV	**Telescopic pole**		
	1.	Material of telescopic pole	Aluminium
	2.	Number of telescopic pole, Nos.	03
	3.	Length of top telescopic pole 20 mm diameter, mm	1200
	4.	Length of middle telescopic pole 25 mm diameter, mm	1400
	5.	Additional length of basal pole 25 mm diameter, mm	1200
V	**Harvesting platform**		
	1.	Material	Aluminium
	2.	Height of harvesting platform, mm	2660
	3.	Dimensions of base platform, mm	610x610
	4.	Base width, mm	1750
	5.	Distance between two straps, mm	300
	6.	Height of safety guard, mm	610
	7.	Weight of harvesting platform, kg	22
VI	**Fruit collecting basket**		
	1.	Covering material of fruit collecting basket	Cotton cloth
	2.	Diameter of fruit collection basket, mm	250
	3.	Depth of fruit collection basket, mm	400
	4.	Thickness of MS rod, mm	08
	5.	Capacity of collection bag on weight basis, kg	11
	6.	Weight of fruit collecting basket, kg	0.5
	7.	Material of belt	Nylon
	8.	Width of belt of fruit collecting basket, mm	35

4.6 Performance evaluation of newly developed Nutmeg harvesting system

The performance and ergonomic evaluation of the newly developed manual Nutmeg harvesting system was found out in terms of harvesting capacity, damage per cent, total harvesting time and labour requirement for Nutmeg fruits and the economics of operation developed manual Nutmeg harvesting system.

4.6.1 Harvesting capacity

The harvesting capacity of newly developed manual Nutmeg harvesting system was found out by the procedure as stated in 3.9.1.1. The results were analyzed statistically and presented in Table 4.7.

The average harvesting capacity of newly developed manual Nutmeg harvesting system was found to be 8.15 (±0.63) kg/h (143.33 ±20.5 Nos./h). In developed manual Nutmeg harvesting system, the fruits could be harvested from a plant up to the height of 8.2 m from ground with comfort and safely without any injury. The harvesting capacity is higher as increased reach of human labour by device and hence more fruits are harvested within less time. The productivity increased due to saving of time and more time utilized for harvesting of fruit due to higher reach. The results confirm similar trend observed by Hamam *et. al.*, (2011) and Sapowadia *et. al* (2001) for other fruit harvesting.

Plate 4.2 harvested fruit

Table 4.7 Harvesting capacity of newly developed harvesting system Cv Konkan Vishwashri, Sughandha, and Shrimanti (for 187 trees)

Trial	Fruit harvesting without platform		Fruit harvesting with platform		Total harvested fruits		Harvesting time, h	Time loss, h	Total harvesting time, h	Harvesting capacity	
	kg	Nos.	kg	Nos.	kg	Nos.				Kg/h	Nos./h
1.	5.56	93.33	13.86	272	19.42	365.33	1.43	0.76	2.19	8.86	167
2.	3.28	56.66	11.72	203.33	15.02	260	1.29	0.67	1.97	7.62	132
3.	5.84	97.33	22.16	363	28.01	460.33	2.28	0.63	3.51	7.98	131
Sum	14.68	247.32	47.74	838.33	62.45	1085.66	5.59	2.06	7.67	24.46	430
Mean	4.89	82.44	15.91	279.44	20.81	361.88	1.86	0.68	2.55	8.15	143.33
SD	1.40	22.41	5.51	80.09	6.60	100.20				0.63	20.5

4.6.2 Damage fruit per cent

The damage fruit per cent was calculated as per the procedure described in 3.9.1.2. The result of the newly developed harvesting system was analyzed statistically and presented in Table 4.8. The average damage fruit per cent of the developed manual Nutmeg harvesting system was found to be 1.33 (±0.42) %. This damage per cent included the mechanical damage and fruits falls during harvesting with and without platform from ground surface. The damage to fruit was least as fruit are collected in net and device reach higher elevation and the chances of damage by harvesting and fall was minimum. The results confirm to similar trends observed by Hamam *et. al.,* (2011).

Table 4.8 Damage fruit per cent of newly developed harvesting system Cv Konkan Vishwashri, Sughandha, and Shrimanti (No. of trees- 187)

Sr. No.	Total harvested fruits, Nos.	Damaged fruit fall during harvesting without platform, Nos.	Damaged fruit fall during harvesting with platform, Nos.	Total damaged fruit, Nos.	Damage fruit per cent
1.	365.33	2.33	2.33	4.66	1.27
2.	260	1.66	3	4.66	1.79
3.	460.33	2.33	2	4.33	0.94
Sum	1085.66	6.32	7.33	13.65	4
Mean	361.88	2.10	2.44	4.55	1.33
SD	100.20	0.38	0.50	0.50	0.42

4.6.3 Total harvesting time

The total harvesting time was calculated as per the procedure given in 3.9.1.3. The total harvesting time that required for locating and detaching the matured fruits by V-shaped picker hook, and collecting them in the fruit collection net was measured and recorded. The total harvesting time includes the lost time for moving tool and platform between nutmeg tree and branches, time required for climbing and getting up down the harvesting platform and also the time required to empty full fruit collecting basket. The results of harvesting time (h), time loss during harvesting (h) and total harvesting time was analyzed statistically and presented in Table 4.7.

The results of average total harvesting time (h) for newly developed manual Nutmeg harvesting system was found to be 0.12 h/kg. This total harvesting time (h) included the harvesting time (h) and time lost during harvesting (h). The less time required may be due to saving the required time for collecting the fruit from ground surface and time to locate and harvest the fruit from tree. The results confirm to similar trends observed by Hamam *et. al.,* (2011) and Savjibhai (2014).

4.6.4 Labour requirement

The labour requirement for newly developed manual Nutmeg harvesting system was calculated as per the procedure given in 3.9.1.4. The labour requirement in Newly developed harvesting system for picking or harvesting the fruits from the tree, to empty the fully loaded net into the fruit collecting basket and to transport the filled fruit collecting basket to the storehouse or further process. It was found that only one person is required to operate the whole developed manual Nutmeg harvesting system.

4.7 Performance evaluation of traditional Nutmeg harvesting methods

The performance of the traditional Nutmeg harvesting method was determined in terms of harvesting capacity, damage per cent, total harvesting time and labour requirement for nutmeg fruits.

4.7.1 Harvesting capacity

The harvesting of Nutmeg fruits was carried out separately by two traditional methods viz., beating of fruits by bamboo stick and hook method. The harvesting capacity of nutmeg fruits by traditional methods was calculated by the procedure as stated in 3.9.2.1. The result of the beating of fruits by bamboo stick method and hook method were analyzed statistically and presented in Table 4.9 and 4.10 respectively.

Table 4.9 Harvesting capacity of beating of fruits by bamboo stick Cv Konkan Sughandha (No. of trees- 445)

Sr. No.	Total harvested fruits		Total harvesting time, h	Harvesting capacity	
	kg	Nos.		Kg/h	Nos./h
1.	3.1	53	1.9	1.63	27.89
2.	4.20	78	2.12	1.98	36.79
3.	3.90	84	2.38	1.63	35.29
Sum	11.2	215	6.4	5.24	99.97
Mean	3.73	71.66	2.13	1.74	33.32
SD	0.56	16.44		0.20	4.764

Table 4.10 Harvesting capacity of hook method Cv Konkan Sughandha (No. of trees- 445)

Sr. No.	Total harvested fruits		Total harvesting time, h	Harvesting capacity	
	kg	Nos.		Kg/h	Nos./h
1.	7.32	102	1.43	5.11	71.32
2.	8.59	144	1.96	4.38	73.46
3.	7.40	120	2.03	3.64	59.11
Sum	23.31	366	5.42	13.13	203.89
Mean	7.77	122	1.80	4.37	67.96
SD	0.71	21.07		0.73	7.74

The total number of harvested fruits by beating of fruits with bamboo stick were 72 while that with hook method were 122.The average harvesting capacities calculated for these methods were 1.74(±0.20) kg/h (34 Nos./h) and 4.37 (±0.73) kg/h (68 Nos./h) respectively. The capacities are lower as more time is lost in locating fruit and fruit collection.

4.7.2 Damage fruit per cent

The damage fruit per cent was calculated as per the procedure given in 3.9.2.2. The result of the traditional methods viz., beating of fruits by bamboo stick and hook method were analyzed statistically and presented in Table 4.11 and 4.12 respectively.

Table 4.11 Damage fruit per cent of beating of fruits by bamboo stick CV Konkan Sughandha (No. of trees- 445)

Sr. No.	Total harvested fruits, Nos.	Total damaged fruit, Nos.	Damaged fruit per cent
1.	53	06	11.32
2.	78	12	15.38
3.	84	15	17.85
Sum	215	33	44.55
Mean	71.66	11	14.85
SD	16.44	4.58	3.29

Table 4.12 Damage fruit per cent of hook method Cv Sughandha (No. of trees-445)

Sr. No.	Total harvested fruits, Nos.	Total damaged fruit, Nos.	Damaged fruit per cent
1.	102	09	8.82
2.	144	14	9.72
3.	120	17	14.16
Sum	366	40	32.7
Mean	122	13.33	10.9
SD	21.07	4.04	2.85

The average damage fruit per cent of the beating of fruits by bamboo stick and hook method of CV Konkan Sughandha were calculated as14.85 (±3.29) and 10.9 (±2.85) per cent respectively. Damage to fruit may be due to harvesting by stick and falling of fruit from height. Similar result was observed by Savjibhai (2014).

4.7.3 Total harvesting time

The total harvesting time was calculated as per the procedure given in 3.9.2.3. The total harvesting time that required for beating, locating and collecting the fruit fallen on ground after harvesting was measured and recorded. The results of harvesting time (h), time loss during harvesting (h) and total harvesting time for beating of fruits by bamboo stick and hook methods were analyzed statistically and presented in Table 4.9, and 4.10 respectively.

The results of average total harvesting time (h) beating of fruit by bamboo stick and hook method were found to be 1.75 h/kg and 4.31 h/kg respectively. This total harvesting time (h) included the harvesting time (h) and time lost during harvesting (h).

4.7.4 Labour requirement

The labour requirement for traditional harvesting methods was calculated as per the procedure given in 3.9.2.4. The labour requirements in traditional harvesting method for harvesting of fruit by bamboo stick and hook method. Similarly labour required to collect the harvested fruit. It was found that two person is required to harvest Nutmeg fruit i.e. one for harvesting and other for collecting the fruit from ground surface. This collected fruit transported from field to store house or further process by use of bag or basket.

4.8.5 Ergonomic evaluation of developed manual nutmeg harvesting system

4.8.5.1 Assessment of physiological cost and drudgery involved in the developed manual Nutmeg harvesting system

The drudgery involved in operation of developed manual nutmeg harvesting system was quantified and the results are discussed as follows.

4.8.5.2 Selection of subjects

Six male subjects were selected for the study. The average age, weight and stature of the subjects were 22.5 (±1.76) years, 57.16 (±5.56) kg and 166.16 (±5.19) cm, respectively for male. The details of male subjects are presented at Appendix IV. The mean values of subject details are given at Table 4.15.

4.8.5.3 Calibration of subjects

Six male subjects were calibrated in the ergonomics laboratory, Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Dapoli. The heart rates and corresponding oxygen consumption rates of the subjects were measured by using energy measurement system (K5b2) while subjects walking on the tread mill ergometer at sub maximal loads to get the relationship between the heart rate and oxygen consumption. The calibration charts for six male subjects are shown in Fig.4.1.

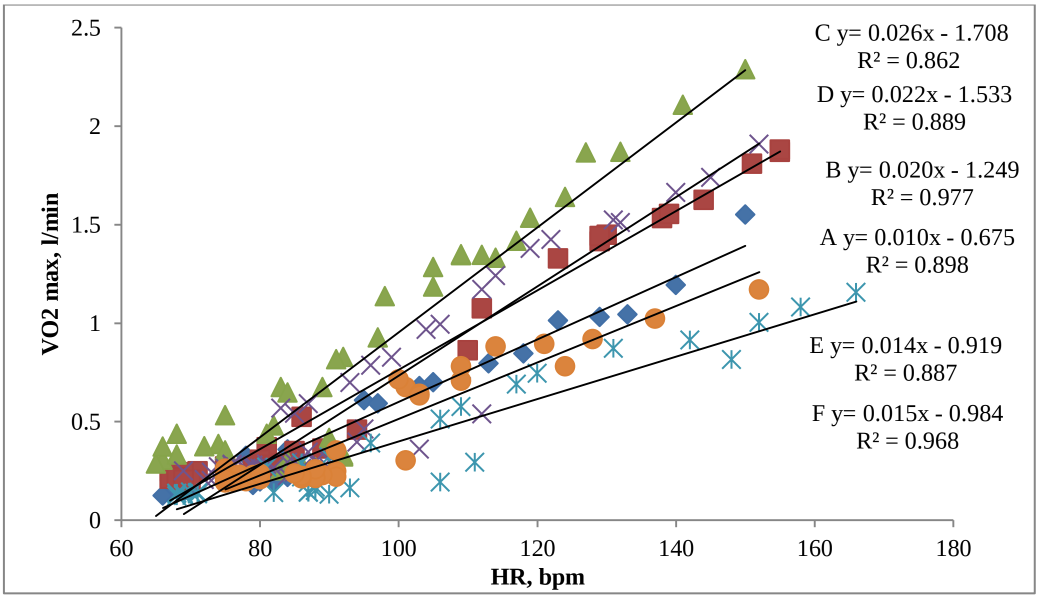


Fig 4.1 Calibration chart for selected subject for evaluation

4.8.5.4 Maximum aerobic capacity (VO2 max)

The maximum heart rate (HR max) of selected male subject was calculated by using equation 3.10. The maximum aerobic capacity (VO2 max) was predicted as explained in Chapter III, section3.9.3.4. The details about maximum heart rates (HR max) and maximum aerobic capacities (VO2 max) for male worker was given at Appendix IV. The HR max was found in the range of 196 to 200 bpm and the corresponding maximum aerobic capacity was found in the range of 0.37 to 1.05 l/min for selected male subjects. The mean HR max and mean VO2 max values for the six selected male subjects were 197.5 (±1.76) bpm and 2.33 (±0.76) l/min, respectively. The mean value of HR max and VO2 max for male are furnished at Table 4.13.

Table 4.13 Subject details and VO2 max during evaluation

Sr. No.	Particulars	Value
1.	No. of subjects	6
2.	Mean age, years	22.5 (±1.76)
3.	Mean stature, cm	166.1667 (±5.19)
4.	Mean weight, kg	57.1667 (±5.56)
5.	Range of HR max, bpm	196 to 200
6.	Mean HR max, bpm	197.5 (±1.76)
7.	Range of VO2 max, l/min	1.28 to 3.38
8.	Mean VO2 max, l/min	2.33 (±0.76)

4.8.5.5 Working heart rate (WHR), oxygen consumption rate (OCR) and energy expenditure rate (EER)

The heart rates (HR) of six male subjects were measured while harvesting of Nutmeg at Department of Horticulture, College of Agriculture, Dapoli, as explained in Chapter III, section 3.9.3.4. The downloaded HR values in the operation with developed manual Nutmeg harvesting system are presented at Appendix IV. The average of 6^{th} to 15^{th} minute of HR values were calculated for each individual subject and considered as working heart rate (WHR). The subject wise values of WHR, oxygen consumption rate (OCR), Energy expenditure rate (EER), work pulse (ΔHR) for male subjects during developed manual Nutmeg harvesting system were calculated and presented in Table 4.14.

Table 4.14 The physiological parameters as WHR, OCR, EER, ΔHR, LCP etc. for male worker during harvesting operation with developed manual Nutmeg harvesting system

Sr. No.	Subject code	Resting HR, Bpm	Working HR, bpm	ΔHR, bpm	LCP < 40, bpm	Working OCR, l/min	% of VO2 max	AWL (35 % of VO2)	EER, kJ/min	Energy grade of work
1.	A	98.25	111.07	11.81	<LCP	0.42	32.81	<AWL	8.76	Light
2.	B	81.78	94.621	12.83	<LCP	0.64	23.27	<AWL	13.76	Moderate
3.	C	74.82	103.31	28.49	<LCP	0.97	28.69	<AWL	20.25	Heavy
4.	D	97.42	117.79	20.37	<LCP	1.05	37.90	>AWL	21.92	Heavy
5.	E	93.62	121.87	28.24	<LCP	0.78	42.16	>AWL	16.28	Moderate
6.	F	80.94	90.50	9.55	<LCP	0.37	18.49	<AWL	7.72	Light
Mean		**87.81**	**106.53**	**18.55**	**<LCP**	**0.70**	**30.53**	**<AWL**	**14.78**	**Moderate**
SD		**(±9.87)**	**(±12.58)**	**(±8.42)**		**(±0.28)**	**(±8.89)**		**(±5.83)**	

From Table 4.14 it was observed that, the mean value of WHR of six male subjects was in the range of 90.50 bpm to 121.87 bpm with mean 106.53 (±12.58) bpm. The corresponding oxygen consumption rate (OCR) for male subjects were predicted using the equations developed for the corresponding calibration charts for subjects. The values of OCR were in the range of 0.37 to 1.05 l/min, with mean 0.70 (±0.28) l/min. The variation in HR and OCR among the subjects for doing the same operation was due to difference in subjects age, weight and stature. The energy expenditure rate (EER) for male subject subjects were as explained in section 3.9.3.8. The ΔHR also known as work pulse was calculated as the difference between WHR and resting HR. The resting HR was taken as ten minute average HR for each individual subject. The ΔHR was in the range of 9.55 to 28.49bpm with mean 18.55 (±8.42) bpm for male workers. The average ΔHR was 27.56 bpm, which was slightly less than the limit of continuous performance of 40 bpm because the newly developed harvesting system is light in weight and easily operate without any discomfort and drudgery.

It was revealed that from Table 4.14 that, among all the subjects was beyond the range of AWL i.e. below 35 % of VO2 max. The percent values of VO2 max for newly developed manual Nutmeg harvesting system was in the range 18.49 to 42.16 %. The mean value of per cent of VO2 max for newly developed manual Nutmeg harvesting system was 30.53 % (±8.89). This indicates that harvesting Nutmeg fruit by newly developed manual Nutmeg harvesting system was below the acceptable workload and Nutmeg harvesting operation with developed system is acceptable to the entire subject selected.

The EER value for subject was in the range of 7.72 to 21.92 kJ/min, with mean 14.78 (±5.83) kJ/min. The energy expenditures of all subjects were different although they followed the same method in same conditions. It might be due to the variation in linear relationship between heart rate and oxygen consumption among the subjects and physiological differences of individuals. The overall energy grade of Nutmeg harvesting by system work was “Moderate” for male worker.

4.8.5.6 Overall Discomfort Rating (ODR)

The overall discomfort score of each subject for harvesting with newly developed manual Nutmeg harvesting system was explained in the section 3.9.3.The values of ODR of subjects while harvesting Nutmeg fruits with newly developed manual Nutmeg harvesting system were presented at Table 4.15.

Table 4.15 Overall discomforts rating (ODR) of subjects while harvesting operation by newly developed manual Nutmeg harvesting system

Sr. No.	Subject code	ODR	Scales
1	A	4	Less than moderate discomfort
2	B	4	Less than moderate discomfort
3	C	5	Moderate discomfort
4	D	5	Moderate discomfort
5	E	4	Less than moderate discomfort
6	F	5	Moderate discomfort
Mean		**4.5**	**Less than Moderate discomfort**

The ODR values for subjects were in the range of 4.0 to 5.0 with mean was 4.5. Mean ODR was scaled as "less than moderate discomfort" during harvesting operation with newly developed manual Nutmeg harvesting system.

4.8.5.7 Body Parts Discomfort Score (BPDS)

The BPDS score was calculated as per the procedure explained in section 3.9.3.for each subject. The average result of the BPDS score calculated for six subjects have been furnished in Table 4.16.

Table 4.16 Body parts discomfort score (BPDS) of subjects while harvesting operation by newly developed manual Nutmeg harvesting system

Sr. No.	Subject code	BPDS Score
1	A	24
2	B	22
3	C	12
4	D	12
5	E	12
6	F	12
Mean		**15.67**

For harvesting with newly developed manual Nutmeg harvesting system, the range of body part discomfort score was 12 to 24 with the mean of 15.67. The maximum number of intensity levels of pain experienced newly developed manual Nutmeg harvesting system was three categories as per the standard procedure.

4.9 Harvesting cost

The cost of harvesting operation was calculated as per the procedure given in 3.9.4. Harvesting of nutmeg fruits was carried out by three different harvesting methods viz., beating of fruits by bamboo stick, hook method and newly developed manual Nutmeg harvesting system. The total harvesting cost was determined by the straight line method and the results were presented in Appendix VI. The traditional and developed harvesting system was evaluated based on harvesting cost also. The detail comparisons of economics of three different harvesting methods are presented in Table 4.17 and graphically represented in Fig 4.2.

Table 4.17 Detail comparison of economics of three different Nutmeg harvesting methods

Sr. No.	Harvesting methods	Harvesting capacity, kg/h	Damage fruit per cent, %	labour require-ment	Cost of operation	
					Rs/h	Rs/kg
1.	Newly developed harvesting system	8.15	1.33	1	48.37	5.93
2.	Hook method	4.37	10.92	2	75	17.16
3.	Beating of fruits by bamboo stick	1.74	14.85	2	75	43.10

The harvesting cost of and the developed harvesting system were found to be 43.10, 17.16 and 5.93 Rs/kg respectively. Thus, the saving of harvesting cost with the use of newly developed harvesting system as compared to traditional harvesting method was 576 and 169 % respectively for beating of fruits by bamboo stick, hook method. This was due to higher harvesting capacity, less time required to harvest matured fruit and less labour required with use of harvesting system. All the performance parameter viz., harvesting capacity, damage fruit per cent, harvesting time, labour requirement and harvesting cost were calculated.

The graphical representation of cost economics has been shown in Fig. 4.2. It was concluded that, traditional method was found more costly as compared to the newly developed manual Nutmeg harvesting system because labour requirement in traditional harvesting method is two i.e. operator wages is high and similarly in developed harvesting system only one operator is needed to harvest the fruit i.e. overall harvesting cost was low and also harvesting capacity was found high as compared to other traditional harvesting method. Thus, the newly developed harvesting system was superior as compared to traditional harvesting method.

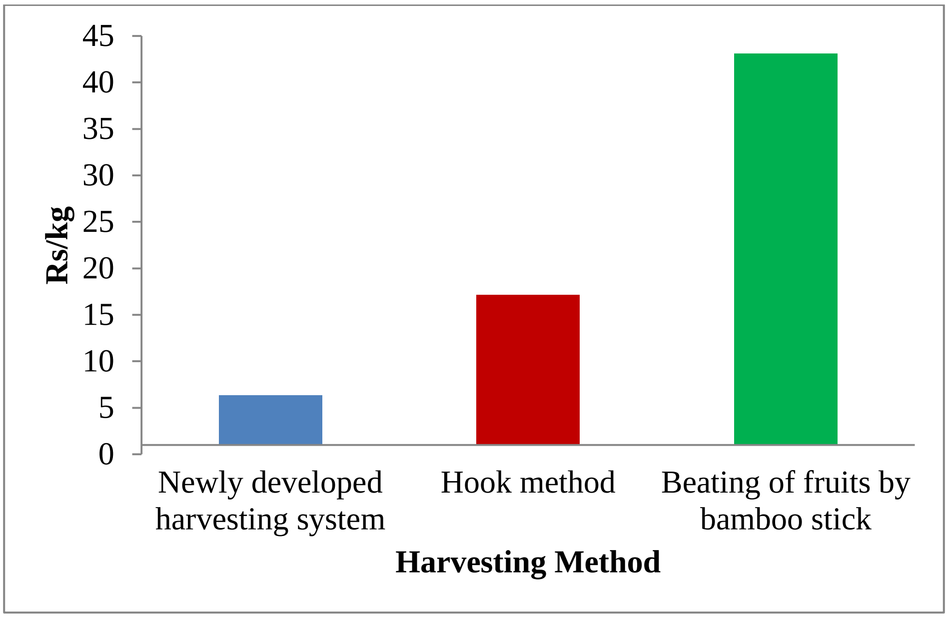


Fig 4.2 Cost economics of different Nutmeg harvesting system

4.10 Comparative performance evaluation of newly developed Nutmeg harvesting system with traditional harvesting method

The comparative performance of newly developed manual Nutmeg harvesting system with traditional Nutmeg harvesting system was found out in terms of harvesting capacity, damage per cent, total harvesting time and labour requirement for nutmeg fruits and also compared the economics of developed manual Nutmeg harvesting system.

4.10.1 Harvesting capacity

The harvesting of nutmeg fruits was carried out by newly developed manual Nutmeg harvesting system. The harvesting capacity of newly developed manual Nutmeg harvesting system was calculated by the procedure as stated in 3.9.1.1. The results with newly developed harvesting system, beating of fruits by bamboo stick and hook method were analyzed statistically and presented in Table 4.7, 4.9 and 4.10 respectively. The average harvesting capacity of newly developed manual Nutmeg harvesting system, beating of fruits by bamboo stick and hook were found to be 8.15 kg/h (143.33 Nos./h), 1.74 kg/h (33.64 Nos./h) and 4.37 kg/h (67.77 Nos./h) respectively. The results of above three harvesting method was graphically presented in fig 4.3. The harvesting capacity was higher with newly developed Nutmeg harvesting system as increased reach of human labour by device and hence more fruits are harvested within less time as compare to traditional harvesting method. The productivity increased due to saving of time and more time utilized for harvesting of fruit due to higher reach. The results confirm similar trend observed by Hamam *et. al* (2011) and Sapowadia *et. al* (2001) for other fruit harvesting.

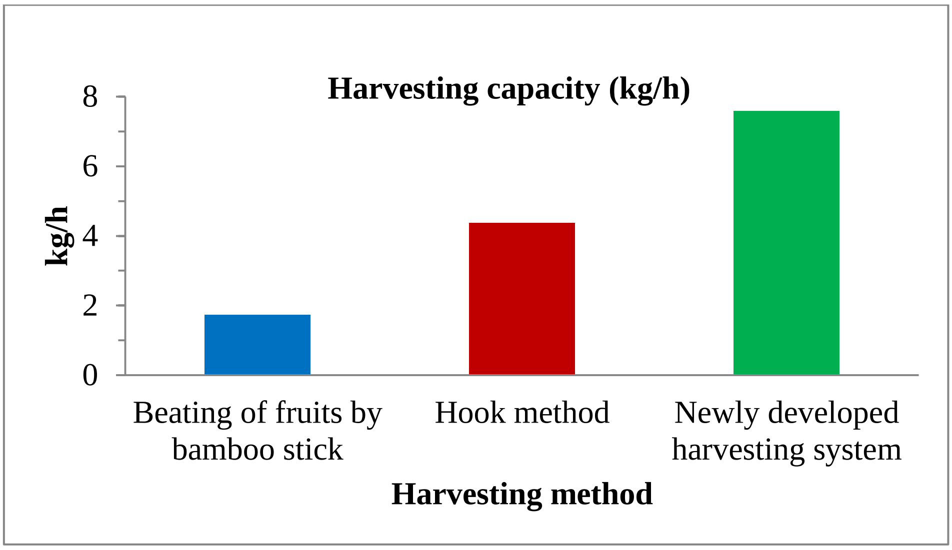


Fig 4.3 Harvesting capacity of different harvesting methods

The above mentioned average harvesting capacity of three different methods was concluded that, the harvesting capacity of Newly developed harvesting system was higher as compared to other two harvesting method and lower harvesting capacity was found in beating of fruits by bamboo stick because of time loss during harvesting was high. In newly developed harvesting system can harvest maximum fruit as compared to other harvesting method and time loss during harvesting was found to be very less as compared to other harvesting system that's why harvesting capacity was found maximum in developed harvesting system. In developed manual Nutmeg harvesting system, the fruits could be harvested from a plant up to the height of 8.2 m from ground with comfort and safely without any injury

4.10.2 Damage fruit per cent

The damage fruit per cent was calculated as per the procedure given in 3.9.1.2. The result of the newly developed harvesting system, beating of fruits by bamboo stick and hook method were analyzed statistically and presented in Table 4.8, 4.13 and 4.14 respectively. The average damage fruit per cent of the developed manual Nutmeg harvesting system was found to be 1.33 %. This damage per cent included the mechanical damage and fruits falls during harvesting with and without platform from ground surface. The average damage fruit per cent of newly developed manual

Nutmeg harvesting system, hook method and beating of fruits by bamboo stick were found to be 1.33, 10.92 and 14.85 per cent respectively. The results of above three harvesting method was graphically presented in Fig 4.4.

The above mentioned average damage fruit per cent of three different methods was concluded that, the damage per cent of Newly developed harvesting system was lower as compared to other two harvesting method and higher damage fruit per cent was found in beating of fruit by bamboo stick method because of there is no fruit collecting mechanism after harvesting fruit. In Newly developed harvesting system the damage fruit per cent was found very low as compared to other conventional harvesting method because of the fruit collecting net was attached to the fruit harvester and after detached fruit from tree and then collected in fruit collection net after that all the fruit transferred in fruit collecting basket. This collected fruit was transported from field to store house or further process by fruit collecting basket. The damage to fruit was least as fruit are collected in net and device reach higher elevation and the chances of damage by harvesting and fall was minimum. The results confirm to similar trends observed by Makawana (2016).

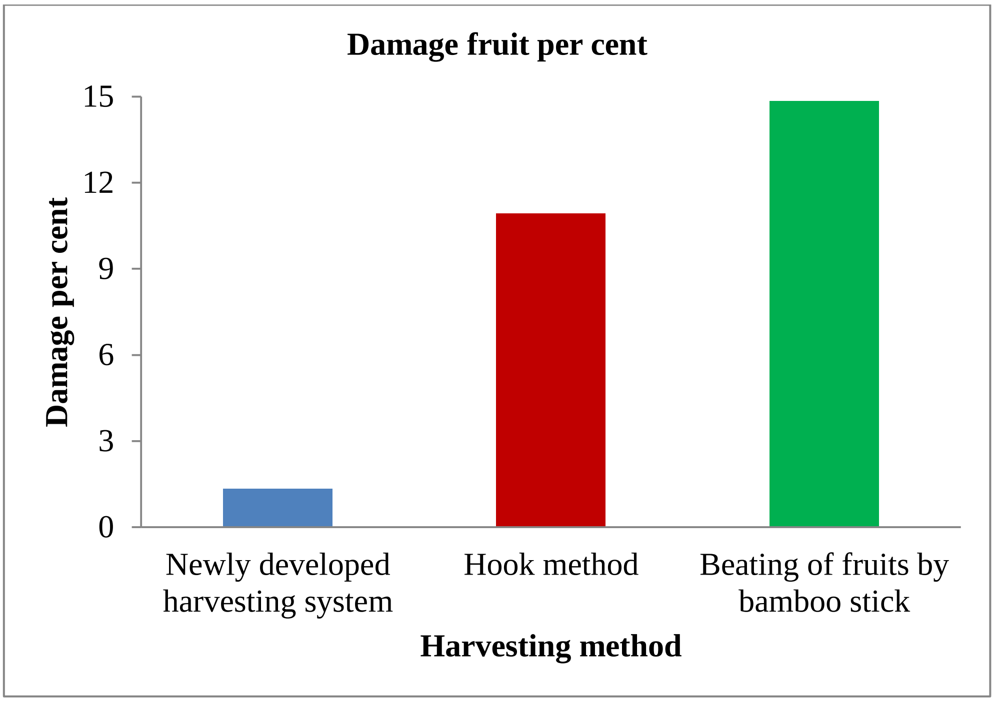


Fig 4.4 Damage fruit per cent of during harvesting

4.10.3 Total harvesting time

The total harvesting time was calculated as per the procedure given in 3.9.1.3. The total harvesting time that required for locating and detaching the matured fruits by V-shaped picker hook, and collecting them in the fruit collection net was measured and recorded. The total harvesting time includes the lost time for moving tool and platform between nutmeg tree and branches, and also the time required to empty full fruit collecting basket. The results of harvesting time (h), time loss during harvesting (h) and total harvesting time for three different harvesting methods was analyzed statistically and presented in Table 4.7, 4.9 and 4.10 respectively.

It is observed that average total harvesting time (h) for three different harvesting method viz., beating of fruit by bamboo stick, hook method and newly developed manual Nutmeg harvesting system was found to be 0.57 h/kg, 0.23 h/kg and 0.12 h/kg respectively. This total harvesting time (h) includes the harvesting time (h) and time lost during harvesting (h). The less time required may be due to saving the required time for collecting the fruit from ground surface and time to locate and harvest the fruit from tree. The results confirm to similar trends observed by Hamam *et. al.,* (2011) and Savjibhai (2014).

4.10.4 Labour requirement

The labour requirement for three different harvesting methods was calculated as per the procedure given in 3.9.1.4. The labour requirement in Newly developed harvesting system for picking or harvesting the fruits from the tree, to empty the fully loaded net into the fruit collecting basket and to transport the filled fruit collecting basket to the storehouse or further process. It was found that only one person is required to operate the whole developed manual Nutmeg harvesting system. The labour requirement in hook and beating of fruits by bamboo stick was found that two persons is required to harvest the matured fruits, one for harvesting the matured fruit and other for collecting the fruits fall during harvesting on ground surface. This collected fruit transported from field to store house or further process by use of bag or basket.

It is observed that, hand picking and beating of fruits by bamboo stick as well as hook method was more labour consuming method as compared to Newly developed manual Nutmeg harvesting system because there is no need of any person for collecting the harvested fruits and fruits fall during harvesting on the ground surface.

CHAPTER V
SUMMARY AND CONCLUSION

The research on "Design and Development of Manual Nutmeg (*Myristica fragrans* Houtt.) Harvesting System" was conducted at department of Farm Machinery and Power, CAET, Dapoli. Based on requirement, manual Nutmeg harvesting system was designed, developed and fabricated. The experiment were conducted for performance evaluation of newly developed manual Nutmeg harvesting system along with ergonomically evaluation and economics of Nutmeg harvesting by new system and traditional method.

5.1 Summary

Nutmeg (*Myristica fragrans* Houtt.) is an important tree spice which produces two different spices namely nutmeg and mace. It is mainly distributed to the low land tropical forests of the world. The major nutmeg growing regions are Guatemala and Indonesia. It is also grown in small scale in India (18,070 MT). Nepal, Bhutan, Grenada, Sri Lanka, Malaysia and Guatemala are world's largest producers of nutmeg. Guatemala's nutmeg production is about 24,000 MT which represents 32.44 per cent of the world's total production. In India it has occupied an area of about 19,670 ha with an annual production of 18,070 MT. It is grown in Tamil Nadu, Kerala, Karnataka, Assam, Andhra Pradesh, Maharashtra and Goa. The production of Nutmeg in the country is still insufficient to meet the demand of the nation and hence a substantial quantity of Nutmeg is imported causing a huge loss of valuable foreign exchange (Anonymous 2016).

Harvesting of Nutmeg fruits is one of the important part in the production of the Nutmeg fruits. Harvesting of Nutmeg fruit is a labour intensive operation, worldwide. In addition, it is a tedious, stoop type job, which is needed to be performed on a seasonal basis during a relatively short time. These combined factors, in addition to the costly operation may contribute detrimentally to the issues of safety, health and quality of harvesting. While in many un-developed countries with, still, cheap and abundant labour, the issue of fruit harvesting does not present yet as a major problem, the declining labour availability and increasing labour costs in the developed countries, combined with more awareness to health and safety issues, make it mandatory to mechanize the fruit harvesting operation.

With the increase emphasis on the fruit production all over the world, demand for the use of the fruit harvester is increasing. The mechanical harvesting is the latest method to improve the fruit harvesting techniques. The mechanical harvester can't be used effectively in the case of central leader type tree due to high energy requirement and excessive vibration.

Konkan region of Maharashtra is one of the major pocket for horticultural crops. Many fruit growers are still facing the problems for fruit harvesting, till date adoption of the traditional methods like beating with bamboo stick or detaching fruit by hook on the trees are adopted for fruit harvesting. Nutmeg trees are grown in mix cropping system and braches are weak and climber cannot climb on tree like mango or coconut for harvesting and other operation. The traditional methods like shaking tree branches was time consuming, drudgeries and unsafe for the operation. Therefore by keeping the specific need in view this project was under taken with the following objective.

1. To develop manual Nutmeg harvesting system.
2. To evaluate the field performance of the developed manual Nutmeg harvesting system.
3. To compare the cost economics of developed manual Nutmeg harvesting system with traditional harvesting method.

Nutmeg fruit bears on tertiary branches and primary and secondary branches are not strong enough to climb on tree. Also, all the Nutmeg fruit does not get matured at a time and thus there arises a need to harvest matured fruit only. Before the development of manual Nutmeg harvesting system, the plant characteristics, physical properties viz., length, breadth, thickness, weight of fruit, mace, nut, pericarp and engineering properties viz., size or equivalent diameter, sphericity, unit volume, projected, surface area, bulk density were measured or calculated. The fruit detachment force for both matured and unmetered Nutmeg fruit detachment was measured. It was found that average FDF/W ratio for matured and unmetered Nutmeg fruit 0.019 kg/g and 0.029 kg/g respectively. Based on requirement, anthropometric data of agricultural of Konkan region and constraints, new harvesting system is designed and developed. It consists of fruit harvester, telescopic pole, harvesting platform, fruit collecting basket. The Nutmeg harvesting by traditional method was carried out to know economics and drawback of traditional harvesting. The performance of newly developed Nutmeg harvesting system was evaluated along with ergonomic evaluation and economics of harvesting operation. The average harvesting capacity, damage fruit per cent and total harvesting time of the developed manual Nutmeg harvesting system was found to be 8.15 kg/h (143.33 Nos./hr), 1.33 % and 0.12 h/kg. One person is required to operate the whole developed manual Nutmeg harvesting system.

5.2 Conclusions

The developed manual Nutmeg harvesting system was evaluated in the field of Department of Horticulture, College of Agriculture, Dr. BSKKV, Dapoli as well as farmers field at the height of plant upto 8.2 m. On the basis of its performance following conclusions were drawn.

1. The performance of newly developed manual Nutmeg harvesting system was found to be superior as compare to traditional Nutmeg harvesting method.
2. The fruit detachment force/weight (FDF/W) ratio for matured Nutmeg fruit was found to be lower as compared to unmatured fruit i.e. FDF/W ratio depends on maturity level of the fruit.
3. The harvesting capacity of traditional methods was found to be 1.74 kg/h (33.32 Nos./h) and 4.37 kg/h (67.96 Nos./h) for beating of fruits by bamboo stick and hook method respectively. Also fruit damage per cent was found to be 10.90 and 14.85 % respectively.
4. The harvesting capacity of newly developed manual Nutmeg harvesting system was found to be 8.15 kg/h or 143.33 Nos./h and the average damage per cent of the developed manual Nutmeg harvesting system was found to be 1.33 % and damage fruit per cent was very low as compared to traditional Nutmeg harvesting devices.
5. The harvesting cost of developed manual Nutmeg harvesting system was found to be low as compared to traditional method due to lower labour requirement and higher output and saving of 576 and 169% of harvesting cost as compared with beating of fruits by bamboo stick and hook method respectively.
6. Only one person is required to operate the developed manual Nutmeg harvesting system and two people are required in traditional Nutmeg harvesting system.
7. Energy expenditure rate (EER) was found to be 14.78 (±5.83) kJ/min during operation of newly developed manual Nutmeg harvesting system.

Also acceptable work load (AWL) and limit of continuous performance (LCP) was found to be less than 40 bpm and 30.53 (±8.89).

8. The harvesting operation of Nutmeg fruit with developed manual Nutmeg harvesting system was less than moderate discomfort as per overall discomfort rating (ODR). Average ODR and BPDS score was found 4.5 and 15.67 respectively.
9. The harvesting operation of Nutmeg fruit with newly developed manual Nutmeg harvesting system was light discomfort as per energy expenditure rate (EER).
10. The newly developed manual Nutmeg harvesting system is recommended for harvesting matured Nutmeg fruit for minimum damage and cost effective harvesting and to make pericarp available for processing.

5.3 Suggestions for future work

The following suggestions may be useful for further improvement in the performance of the manual Nutmeg harvesting system and its efficient and economical use.

1. The developed manual Nutmeg harvesting system should be tested for its suitability on the other horticultural crops viz., Kokum, Aonla, Citrus, Lemon, Guva, Mango etc.
2. Another telescopic pole with sufficient strength to balance the load while harvesting fruits in upper most zone of the tree may be tried.
3. To easily locate the matured fruit, multi blade V shaped picker hook may be tried.
4. One tool box should be provided to harvesting platform.
5. For easily transportation purpose the transport wheel may be provided.
6. Capacity of fruit collecting basket should be increased upto 20 kg to avoid loss of time.

CHAPTER VI

BIBLIOGRAPHY

Abou EI-Kheir, M. M. 1993. Mechanical arm for lime -fruit picking. *Misr J. Ag. Eng,* 10 (3):385-401.

Abou EImagd, A. E., Human, A. S., EI- Saadany, M. A and EI-Khawaga, S. E. 2002. Design of a cone end detacher for orange picking, *Misr. J. Agril. Engg.* 19(2):191-507.

Adetan, D.A., Adekoya L.O., and Oladejo K. A. 2007. An Improved Pole-and-Knife Method of Harvesting Oil Palms. *Agricultural Engineering International: the CIGR E-journal.* Manuscript PM 06 027. Vol. IX.

Ahmed N. and Francesco G. P. 2014. Proposed Harvester Model for Palm Date Fruit. *Journal of Agricultural Technology* 2014 Vol. 10(4): 817-822.

Anandaraj, M. S., Devasahayam, T., John Zachariah, B. Krishnamoorthy, P. A. Mathew and J. Rema. 2005. Nutmeg (Extension Pamphlet). Indian Institute of Spices Research, Kozhikode.

Anonymous, 1966. Annual Report of Research Testing and Training Center, Jorhat, Assam.

Anonymous, 1989 (a). Annual report for Himsagar mango fruits. Bidhan Chandra Krishi Viswavidyalaya (BCKV), Kalyani., West Bengal.

Anonymous, 1989 (b). A comparative study of methods of harvesting Rasapuri and Totapuri mango. Indian Institute of Horticulture Research, (IIHR)., Banglore. Annual Report 1989.

Anonymous, 1994. Annual report on farm tools and impliments. Dr. Balasaheb Sawant Konkan Krishi Vidhyapeeth Dapoli., Maharastra.

Anonymous, 1996. An improved mango harvester was designed and developed at Indian Agriculture Research Institute., Delhi. Annual Report 1996.

Anonymous, 1998. Mango harvester was designed and developed at Dr. Balasaheb Sawant Konkan Krishi Vidhyapeeth Dapoli., Maharastra. Annual Report 1998.

Anonymous, 2001. Annual Report of Research Testing and Training Center, Junagadh Agricultural University., Junagadh.

Anonymous, 2009. Anthropometric survey and strength data of agricultural worker.

Anonymous, 2013. Handbook of Agricultural Engineering, *Indian Council of Agricultural Research (ICAR)., New Delhi publication* 178-179.

Anonymous, 2015. Orgeon OSHA standards and Technical Research, USA, pp. 25.

Anonymous, 2016. www.mapsofworld.com/world-top-ten/nutmeg-roducingcountries.html accessed on 9 February, 2016.

Anonymous, 2017. Report on good practices in agriculture: Social partners participation in the prevention of muscular skeleton disorders. Fruit harvesting accessed on www.agri-ergonomics.eu on 24 January, 2017.

Anonymous, 2018. www.buckling.wikipedia.org. accessed on 22 July, 2018.

Anonymous, 2018. www.bucklingload.org. accessed on 22 July, 2018.

Anonymous, 2018. www.oshausdepartment.com accessed on 7 March, 2018.

Borg, G. 1985. An introduction to Borgs RPE scale. Ithaca, NY: *Movement Publication*. pp. 237.

Changon, R., J. B. Boutin, Eng. And F. Sylviain Eng. 2007. Development of a branch shaker to forest seabuckthorn, 3rd international Seabuckthorn Association Conference. 31-38.

Chhotala V. J. 2014. Design and development of a device for black berry harvesting. Unpublished M. Tech thesis, College of Agricultural Engineering and Technology, Junagadh.

Corlett, E. N. and R. P. Bishop.1976. A technique for assessing postural discomfort. *Ergonomics*, Vol.19: pp. 175-182.

Divekar, S. P., Thakor, N. J., Mulla, H. Y., and Sawant, M. V., 2011. Effect of drying on physical properties of nutmeg. E*ngineering and Technology in India*, Volume 2 Issue (1 & 2); (April & October, 2011); Page : 18-23.

Fulmer Scott, M. S., Laura Punnett, ScD., Tucker Slingerland and Giulia Earle-Richardson. 2000. Ergonomic exposures in orchard fruit harvesting. The 128th Annual Meeting of APHA.

Fulmer, Punnett, L. Slingerland, D. T. and Giulia., R. 2002. Ergonomic exposures in apple harvesting: preliminary observations. *American Journal of Industrial Medicine Supplement.* 2:3-9.

Futch, S. H., and F. M. Roka. 2005. Continuous canopy shake mechanical harvesting systems. EDIS. UF/IFAS. Gainesville, Florida Cooperative Extension service, Institute of Food and Agricultural Sciences, University of Florida. Published March 2005.

Gangopadhyay, S., Das, B., Das, T., and Ghoshal, G. 2005. An ergonomic study on posture-related discomfort among preadolescent agricultural workers of West Bengal, India. *International Journal of Occupation and Safety Ergonomics.* 11 (3): 315-322.

Gite, L. P. and G. Singh. 1997. Ergonomics in agricultural and allied activities in India. Central Institute of Agricultural Engineering, Bhopal.

Grandjean, E. 1982. Fitting the task to the man. *An Ergonomic Approach*. Taylor & Francis Ltd, London: 77-81.

Gupta, R. A., Mohrial, P., Satasiya, R. M., and Gontia, N. K. 2004. Development and testing of a tractor-mounted Positioner for mango harvesting. *Agri. Mechanization in Asia, Africa and Latin America,* 35 (1): 28-32.

Hamam, A. S., M. E. EL-Iraqi, S. E. EL Khawaga and T. R. Awais. 2011 (b). Design and evaluation of mechanical picking head for peach fruits harvesting, *Egypt. J.Agric. Res.*, 89(4), 2011.

Hamam, A. S., M. E. EL-Iraqi, Y. Sharibim and T. R. Awais. 2011 (a). Design and evaluation of mechanical picking heads for citrus fruits harvesting, *Egypt. J.Agric. Res.*, 89(4), 2011.

Hamedon, Zamzuri, Nafis, M.O.Z. and Ghazalli, Z. and Noor, M. M. (2008). Design fabrication and testing of new invented spring sickle pole "ZappIt" for Palm Harvesting. *National Conference on Design and Concurrent Engineering.* 273-278.

Jaouen. G., Almeras. T., Coutand. C. and Fournier. M., 2007 How to accurately determine tree's buckling risk with only a few measurements? *American Journal of Botany* 94(10): 1583–1593.

Jelani, A. R., and Hitam, A., 2000. Design and Evaluation of an Improved Aluminium Harvesting Pole (Hi-Reach) for Tall Palm Harvesting. *Oil plam Bullletin* 44: 29-38.

Jelani. A. R., Rahim. S., and Ahemad. H., 1998. The effects of physical characteristics of aluminium pole on the harvesting productivity of tall palms. *PORIM Bulletin No.* 36: 13-23.

Khurmi. R. S., 2001. Strength of materials. *21st edition. S.Chand and company ltd., New Delhi.* 269-340.

Kolhe K. P. and Jadhav B. B. 2011. Testing and performance evaluation of tractor mounted hydraulic elevator for mango orchard. *American Journal of Engineering and Application Sciences.* 4(1):179-186.

Kolhe, K. P. 2009. Development and testing of tree climbing and harvesting device for mango and coconut trees. *Indian Coconut Journal.* 52(3):15-20.

Kolhe, K. P. 2010. Mechanized harvesting, the need of coconut growers in India. *Indian Coconut Journal.* 53(2):15-19.

Kroemer, K .H .E., H. J. Kroemer, and K.E. Kroemer-Elbert. 1997. Engineering physiology. Van Nostrand Reinhold. New York. pp. 193-228.

Kuta. L., Ciez. J. and Moltek. M. 2015. Musculoskeletal load assessment of farmers during selected agricultural works. *6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015*. *Procedia Manufacturing* 3(2015): 1696 – 1703.

Li, M., Davies, D.C. and Barbosa-Cavovas G.B. 1998. *Engineering properties of foods and other Biological materials (A Laboratory Manual).* ASAE press, St. Joseph, MI.

Maegawa, H., Kiriyama, H. and Kurozumi, T. 2000. Ergonomical studies on redesign of working conditions in agriculture. Relationship between bed height, worker stature and working posture in strawberry culture. *Bulletin of The Nara Agricultural Experiment Station.* 31: 1- 8.

Makwana A. D. 2016. Design and development of a device for harvesting of fruits from thorny trees. Unpublished M. Tech thesis, College of Agricultural Engineering and Technology, Junagadh.

Miles, J. A., and W. E. Steinke. 1996. Citrus Workers Resist Ergonomic Modifications to Picking Ladder. *Journal of Agricultural Safety and Health.* 2 (1): 7-15.

Millar, W.M. 1987. Physical properties data for post-harvest handling of florida citrus, *Appl. Eng. Agric.,* 3(1):123-128.

Mohamad, I. A. Ahmad, H. H. Hind M. A. 2006. Design and fabrication of a small-scale fruit picker of adjustable height. *Journal of Agricultural Mechanization in Asia, Africa and Latin America.* 37 (4):49-51.

Mohesnin, N. N. 1950. *The physical properties of plant and animal materials.* Gordan and Breach, Science Publishers, Inc. New York,: 51-78.

Murrel, K. P. H. 1963. Human performance in industry. Reinhold Publishing Corporation, New York.

O'Brien, M.B., F. Cargil and R.B. Friendly. 1983. Harvesting and handling fruits and Nuts. *Avi. Publication comp. Inc., West port,* CT, USA.

Patange, G. S., Shinde, V. B., Badgujar, P. D., and Gholap, B. S. 2013. Development and comparative performance of manually operated tamarind harvesters. *Journal of Engineering and Technology in India.* 4(1): 7-10

Paul, L., Jenkins, David Strogatz., Erin M. Bell and John J. May. 2006. Development and initial assessment of objective fatigue measures for apple harvest work. *Applied Ergonomics.* 37 (6): 719-727.

Powar, A. G., Badhe, V. T., Nadkarni, H. R. 2003. Horticultural tools and equipment's of BSKKV, Dapoli. Proceedings of Mega mango festival held at Mumbai. pp. 15-17.

Prussia, S. E. 1985. Ergonomics of manual harvesting. *Applied Ergonomics.* 16 (3): 209-15.

Ratnakumar, P. K. 2013. Development of a tool for effective mango harvesting to reduce post harvest loss. *International Journal of Processing and Post Harvest Technology.* Vol. 4(2): 135-137.

Richardson, G. Earle, Fulmer S., Jenkins P., Mason, C., Bresee, C. and J. May. 2004. Ergonomic Analysis of New York Apple Harvest Work Using a Posture-Activities-Tools-Handling (PATH) Work Sampling Approach. *Journal of Agricultural Safety and Health.* 10(3): 163-176.

Safdari A., H. R. Ghassemzadeh, SH. A. Abodollahpour and H. Ghafari. 2010. Design and construction and evaluation of a portable limb shaker for almond tree. *Australian Journal of Agricultural Engineering,* 1(5): 179-183.

Saha, P. N., S. R. Datta, P. K. Banergy, and G. Narayane.1979. An acceptable workload from a modified scale of perceived exertion, *Ergonomics*. 37, pp. 485-491.

Sakakibara, H., Miyao, M., Kondo, T. and Yamada, S. 1995. Overhead work and shoulder-neck pain in orchard farmers harvesting pears and apples. *Ergonomics.* 38: 700-706.

Sanders, K. F. 2005. Orange harvesting system review. *Bio-system Engineering power and machinery*, 90(2):115-125.

Sapowadia, B. D., Gupta, R. A., Patel, H. N. and Pund, S. R. 2001. Design and development of a mango harvesting device. *Agricultural Mechanization in Asia, Africa and Latin America*, 32(1):35-37.

Sapowadia, B. D., Gupta, R. A., Patel, H. N., and Pund, S. R. 2001. Design and development of mango harvesting device. *Agricultural Mechanization in Asia, Africa and Latin America.* 32 (1): 31-34.

Savjibhai K. P. 2016. Development and performance evaluation of a mango harvesting device. Unpublished M. Tech thesis, College of Agricultural Engineering and Technology, Junagadh.

Seamount, D.T., and Optiz, K. W. 1973. The Auto Picker: A two-man positioning machine. *Cltrograph*, 59(1):23-27

Shinde, S. J., Jature, S. D., Hiwale, B. G. 2012. A textbook on production technology of fruits and vegetables. *Shri Rajlaxmi Prakashan.* 162-164.

Siwalak, P., Sriwai, S. and Thongchai, K. 1989. Development a hand held and operated single fruit harvesting device and a mango stem picker. *Thal. Agriculture Research Journal.,Thailand.* 07(1-3):69-78.

Soliman, A. H., EL-Iraqi, M.E., Sharobeem, Y. and Awais, T. R. 2012. Development and evaluation of mechanical picking heads for citrus fruits harvesting. *Agricultural Mechanizations in Asia, Africa and Lain America.* 43(2): 50-58.

Torregrosa, A., Martin, B., Garcla Brunton. J. and Bernad, J. J. 2008. Mechanical harvesting of processed peaches. *Applied Engineering in Agriculture.* 24(6):723-729.

Valdez, J. A. 1999. Development a fruit harvesting to minimize the damage and ease mango harvesting operation. *Philippine Council for Agricultural, Forestry and Natural Resource and Development, Loss Bonos.* pp. 22-33.

Wade H. V. 2010. Ergonomic evaluation of traditional guava harvesting system. Unpublished M. Tech thesis, college of Technology and Engineering, MPAUT Udaipur.

Whitney, J. D., Wheaton, T. A., Castle, W. S. and Tucker, D. p. H. 1996. Orange grove factors affect manual harvesting Rates. *Transactions of the American Society of Agricultural Engineers*, 39(2):399-405.

CHAPTER VII

APPENDICES

APPENDIX I

A. Nutmeg plant characteristics

(Variety- Konkan Vishwashri, Age of the plant 9 year, plant to plant spacing and row to row spacing 4 m)

Sr. No.	Height of tree, m	Bark height, m	No. of fruit percentage, %		
			Inside	Outside	Top
1	9.5	1.82	25	60	15
2	7.3	1.32	20	62	18
3	8.2	1.57	25	65	10
4	10.5	2.34	23	68	9
5	10.7	2.5	25	63	12
6	8.3	1.4	25	64	11
7	11	2.78	22	61	17
8	7.8	1.34	22	65	13
9	8.2	1.56	19	63	18
10	11.2	2.86	21	64	15
11	9.7	1.65	18	62	20
12	9.5	1.35	28	60	12
13	10.1	1.98	21	65	14
14	8.8	1.5	26	63	11
15	11.1	2.64	25	65	10
16	8.18	1.5	25	60	15
17	8.58	1.2	23	62	15
18	10.34	2.5	29	66	5
19	10.59	2.3	27	68	5
20	10.34	1.9	24	63	13
21	9.76	1.3	21	65	14
22	9.57	1.57	29	64	7
23	9.34	1.73	25	68	7

24	8.81	1.2	27	69	4
25	7.57	2.2	27	61	12
26	7.94	1.2	23	67	10
27	7.55	1.8	21	64	15
28	8.98	1.52	20	68	12
29	8.98	1.22	21	64	15
30	8.28	1.8	28	67	5
Mean	**9.22**	**1.78**	**23.83**	**64.2**	**11.96**
Max	**11.2**	**2.86**	**29**	**69**	**20**
Min	**7.3**	**1.2**	**18**	**60**	**4**
Range	**3.9**	**1.66**	**11**	**9**	**16**
SD	**1.16**	**0.50**	**3.04**	**2.60**	**4.18**
CV %	**12.57**	**28.35**	**12.75**	**4.05**	**35.00**

APPENDIX II

A) Physical Properties of Nutmeg (Variety- *Konkan Sughandha*)

Sr. No.	Length, mm	Width, mm	Thickness, Mm	Wt. of fruit, g	Wt. of mace, g	Wt. of nut, g	Wt. of mace +nut, g	Wt. of pericarp, g
1	65.48	60.58	49.09	81	3.8	7.4	11.2	69.8
2	74.38	52.97	44.03	80.05	3.4	10.2	13.6	66.45
3	60.09	56	48.86	70.1	2.9	7.9	10.8	59.3
4	60.04	58.25	52.28	100.1	3.5	13.8	17.3	82.8
5	58.18	56.7	43.48	75.6	3	12.9	15.9	59.7
6	70.56	59.94	45.81	84.8	6.2	13.5	19.7	65.1
7	61.76	61.66	52.1	98.3	4.5	13.6	18.1	80.2
8	52.62	45.85	42.6	46.1	1.4	7.5	8.9	37.2
9	60.8	62.92	53.28	99.2	4.6	15	19.6	79.6
10	58.44	63.17	51.85	89.8	4	10.8	14.8	75
11	68.8	53.65	47.54	78	2.6	9.7	12.3	65.7
12	65.06	57.26	45.81	80.4	3.1	8.7	11.8	68.6
13	60.61	65.2	54.32	106.6	4.5	13.3	17.8	88.8
14	60.48	51.58	43.4	58.8	2.4	7.1	9.5	49.3
15	67.81	54.13	42.13	64	2.7	10.7	13.4	50.6
16	63.5	63.44	50.32	99.05	4.3	13.1	17.4	81.65
17	54.45	53.83	42.31	55.5	4	10.6	14.6	40.9
18	53.03	50.75	41.25	52.08	3.6	14.1	17.7	34.38
19	70.66	58.21	49.2	89.3	5.1	13.1	18.2	71.1
20	64.75	56.32	51.77	83.6	3.8	10.3	14.1	69.5
21	65.27	54.5	46.71	72.5	1.9	7.7	9.6	62.9
22	68.46	54.9	45.03	77.3	4.9	11.4	16.3	61
23	66.62	53.93	45.15	71.2	3.7	9	12.7	58.5
24	55.2	47.18	44.18	52.2	1.6	7.7	9.3	42.9
25	59.45	57.5	52.6	87	3.9	10.6	14.5	72.5
26	74.64	50.11	44.77	74.2	2.6	10.1	12.7	61.5
27	70.57	49.95	44.19	71.3	2.7	11.6	14.3	57
28	77.22	54.01	48.36	88.8	3.9	13	16.9	71.9
29	71.22	53.82	46.45	88.4	3	14.1	17.1	71.3
30	71.64	56.92	46.64	87.2	4.9	10.2	15.1	72.1
31	79.01	51.15	47.97	76.1	3.3	12	15.3	60.8
32	67.55	44.34	39.11	54.01	2.9	7.7	10.6	43.41
33	68.92	53.3	43.73	71.4	3.6	9.7	13.3	58.1
34	71.28	56.27	44.65	79.3	4.3	8.8	13.1	66.2
35	75.11	57.25	44.61	69.9	4	8.4	12.4	57.5
36	66.34	55.96	48	68.7	2.8	8.5	11.3	57.4
37	53.37	57.85	46.65	68.6	3	7.9	10.9	57.7
38	57.19	51.93	44.56	65.7	2.4	9.8	12.2	53.5

39	63.37	46.72	39.47	49.6	1.8	6	7.8	41.8
40	73.71	52.9	47.62	84.6	4.3	10.7	15	69.6
41	76.62	52.79	45.75	80.9	3.5	9.9	13.4	67.5
42	74.84	49.22	43.32	69.8	2.7	8.6	11.3	58.5
43	61.78	49.3	40.13	48.5	2.6	5.6	8.2	40.3
44	76.09	57.39	47.93	84.9	4.2	11.3	15.5	69.4
45	72.84	51.08	41.91	64	2.9	8.8	11.7	52.3
46	75.68	54.63	45.31	78.2	2.8	8.9	11.7	66.5
47	73.84	53.37	44.29	88.5	2.7	11.6	14.3	74.2
48	60.88	50.48	42.36	56.2	2.6	6.5	9.1	47.1
49	59.81	54.01	49.35	72.6	3.5	10.2	13.7	58.9
50	57.21	45.47	41.72	47.9	1.4	8.5	9.9	38
Mean	**65.94**	**54.41**	**46.07**	**74.83**	**3.35**	**10.16**	**13.51**	**61.31**
Max.	**79.01**	**65.2**	**54.32**	**106.6**	**6.2**	**15**	**19.7**	**88.8**
Min.	**52.62**	**44.34**	**39.11**	**46.1**	**1.4**	**5.6**	**7.8**	**34.38**
Range	**26.39**	**20.86**	**15.21**	**60.5**	**4.8**	**9.4**	**11.9**	**54.42**
SD	**7.28**	**4.740**	**3.71**	**15.03**	**0.99**	**2.34**	**3.05**	**12.90**
CV %	**11.051**	**8.71**	**8.05**	**20.08**	**29.73**	**23.08**	**22.56**	**21.03**

B) Physical Properties of Nutmeg (Variety- *Konkan Shrimanti*)

Sr.No.	Length, mm	Width, mm	Thickness, mm	Weight of fruit, g	Weight of mace, g	Wt. of nut, g	Wt. of mace +nut, g	Wt. of pericarp, g
1	66.4	43.63	39.95	50.7	1	8.5	9.5	41.2
2	60.85	59.25	50.86	84.9	2.7	6	8.7	76.2
3	60.55	63.28	53.86	102.9	5.4	11	16.4	86.5
4	67.66	62.7	52.88	99.8	5	13.7	18.7	81.1
5	70.9	57.18	54.29	98.4	5.8	21.4	27.2	71.2
6	71.36	51.13	43.88	72.9	3	8.3	11.3	61.1
7	56.23	59.96	53.3	92.4	3.2	13.8	17	75.4
8	74.73	53.77	43.57	75.1	3	10.6	13.6	61.5
9	53.75	47.5	38.77	46.6	3.3	7.6	10.9	35.7
10	54.27	49.42	41.86	50.3	2.7	5	7.7	42.6
11	53.25	50.11	45.19	57.3	2.4	9	11.4	45.9
12	71.33	51.48	43.17	65.2	2.4	10.5	12.9	52.3
13	57.97	60.15	52.16	94.4	4.6	11.1	15.7	79.2
14	63.7	51.01	42.22	62.3	2.3	11.8	14.1	48.2
15	46.78	47.73	44.17	50	2.2	6.3	8.5	41.5
16	57.5	48.03	39.36	45.6	1.2	6.6	7.8	38.8
17	62.22	44.14	35.5	39.4	3.4	4.7	8.1	31.3
18	53.63	43.43	39.7	42	2.3	7.2	9.5	32.5
19	51.94	48.25	37.88	38.3	3	5.1	8.1	30.2
20	54.43	58.96	48.51	81.7	3.7	12.5	16.2	65.5
21	43.56	49.92	45.89	54.3	1.8	6	7.8	46.5
22	61.66	56.62	46.79	70.8	4.7	9.2	13.9	56.9
23	74.66	56.68	47.2	87.7	5.1	10.7	15.8	71.9
24	52.34	44.39	33.8	31.8	3.4	2.1	5.5	26.3
25	68.45	57.83	48.91	76.6	3.5	10.9	14.4	62.2
26	55.15	51.24	41.37	49.2	3	7.7	10.7	38.5
27	49.68	47.84	37.36	38.4	3.6	4.6	8.2	30.2
28	58.17	56.09	50.36	83.7	3.7	11	14.7	69
29	54.02	41.69	36.88	38.2	0.7	6.1	6.8	31.4
30	52.64	45.12	37.5	43	1.3	6	7.3	35.7
31	52.91	44.17	36.23	36.5	2.4	4.4	6.8	29.7
32	53.98	58.08	48.1	73.4	2.7	8.7	11.4	62
33	56.58	46.54	39.09	48.1	2.9	12.2	15.1	33
34	64.02	50.15	46.06	53.5	4.6	8.4	13	40.5
35	52.83	38.71	34.99	31.1	0.7	3.2	3.9	27.2
36	54.07	43.55	36.24	34.9	1.8	5.7	7.5	27.4
37	52	38.97	35.01	30.2	1.1	2.3	3.4	26.8
38	48.29	48.99	41.01	46	2.7	4.9	7.6	38.4
39	54.12	44.59	35.97	39.6	1.4	6.6	8	31.6

40	47.85	51.1	41.92	50.2	2.8	6.9	9.7	40.5
41	72.67	50.32	48.92	78.3	3.8	17.2	21	57.3
42	50.91	46	68.69	40.4	1.4	5	6.4	34
43	59.6	47.12	42.17	56.4	3.3	10.2	13.5	42.9
44	47.83	49.17	41.26	47.3	2.1	6.8	8.9	38.4
45	61.65	59.63	51.19	90.3	4.7	12.7	17.4	72.9
46	47.93	48.9	43.64	51.6	2.1	7.2	9.3	42.3
47	49.25	43.57	36.23	35	1.7	4.8	6.5	28.5
48	52.7	47.81	43.79	53.3	3.6	13	16.6	36.7
49	51.53	43.53	35.84	32.9	2.3	4	6.3	26.6
50	50.12	47.97	38.12	42.1	3.5	8.9	12.4	29.7
Mean	**57.21**	**50.14**	**43.43**	**57.9**	**2.9**	**8.36**	**11.26**	**46.65**
Max.	**74.73**	**63.28**	**68.69**	**102.9**	**5.8**	**21.4**	**27.2**	**86.5**
Min.	**43.56**	**38.71**	**33.8**	**30.2**	**0.7**	**2.1**	**3.4**	**26.3**
Range	**31.17**	**24.57**	**34.89**	**72.7**	**5.1**	**19.3**	**23.8**	**60.2**
SD	**7.92**	**6.18**	**6.83**	**21.09**	**1.23**	**3.80**	**4.68**	**17.44**
CV %	**13.85**	**12.33**	**15.73**	**36.43**	**42.66**	**45.47**	**41.60**	**37.38**

C) **Physical Properties of Nutmeg (Variety- *Konkan Vishwashri*)**

Sr. No.	Length, mm	Width, mm	Thickness, mm	Weight of fruit, g	Weight of mace, g	Wt. of nut, g	Wt. of mace +nut, g	Wt. of pericarp, g
1	78.11	53.28	44.3	78	3	10.6	13.6	64.4
2	59.89	45.64	36.15	37.5	2.4	5.3	7.7	45.2
3	69.71	50.71	42.36	58.6	3.9	6.4	10.3	48.3
4	58.41	40.1	31.72	29.5	1.8	4.7	6.5	23
5	75.53	54.42	45.76	76.5	4.3	10.5	14.8	61.7
6	70.92	55.13	42.17	68.6	4.6	8.5	13.1	55.5
7	57.15	46.16	41.23	50.5	1.6	6.8	8.4	42.1
8	64.95	46.88	38.79	46.7	2.9	5.4	8.3	38.4
9	76.83	56.55	45.04	76.7	3.4	11.2	14.6	62.1
10	72.22	53.63	71.4	70.8	4.1	8.3	12.4	58.4
11	51.87	40.14	34.95	29.8	2	6.5	8.5	23.3
12	67.12	60.18	49.65	86.2	4.6	10.7	15.3	70.9
13	76.73	52.61	44.9	75.7	3.4	8.2	11.6	64.1
14	51.53	40.78	33.39	28.4	2.5	4.2	6.7	21.7
15	58.54	39.38	32.46	29.1	2	2.9	4.9	24.2
16	56.78	42.9	35.42	33.7	2.4	4.3	6.7	27
17	58.7	43.58	37.52	36.1	1.8	5	6.8	29.3
18	67.21	44.8	39.27	52.9	2.1	6.8	8.9	44
19	58.07	41.75	35.56	34.5	2.3	4.7	7	27.5
20	51.14	39.61	33.28	27.1	1.7	3.4	5.1	22
21	68.64	56.6	44.94	69.7	3.2	7.5	10.7	59
22	61.75	45.46	37.92	41	2.7	5.5	8.2	32.8
23	60.63	53.79	46.58	66.9	3.2	7.3	10.5	56.4
24	49.82	40.1	32.56	27.6	2.1	4.1	6.2	21.4
25	59.75	43.5	36.54	36.9	1.3	6.1	7.4	29.5
26	43.73	45.86	39.4	39.2	1.6	4.9	6.5	32.7
27	63.76	50.25	41.24	41.24	4.3	7.2	11.5	39
28	54.14	44.8	39.44	39.44	1.6	3.4	5	35.1
29	63.25	45.29	39.23	39.23	2.8	5	7.8	35.7
30	51.96	39.55	32.78	32.78	1.6	4	5.6	20.2
31	57.18	38.76	35.02	35.02	1.4	4.3	5.7	24.7
32	66.68	48.9	37.24	37.24	2.8	6.5	9.3	39.3
33	56.4	42.74	36.37	36.37	2	6	8	26.2
34	59.37	45.87	38.52	38.52	3.2	4.7	7.9	33.4
35	53.56	38.34	34.82	34.82	1.8	4.1	5.9	25.4
36	61.7	54.48	43.4	43.4	2.8	6.9	9.7	50.1
37	61.35	42.51	31.69	31.69	2	2.9	4.9	25.5
38	48.06	36.41	29.95	29.95	1.2	2.7	3.9	17.2

39	52.54	42.46	33.34	33.34	0.8	6.3	7.1	23.4
40	48.18	41.13	33.3	33.3	1.8	4.1	5.9	22.5
41	52.65	45.09	40.23	40.23	2	5.4	7.4	32.9
42	47.55	36.6	30.29	30.29	1.4	3.4	4.8	17.5
43	57.83	41.47	31.32	31.32	2.2	3.2	5.4	23.8
44	55.31	36.42	35.67	35.67	1.1	5.7	6.8	24.7
45	43.94	34.26	30.2	30.2	1	3	4	16.3
46	50.61	37.87	31.4	31.4	1.6	3.8	5.4	20.3
47	70.72	45.6	43.04	43.04	2.3	7.6	9.9	55.6
48	72.75	45.09	42.9	42.9	2.8	10.5	13.3	55
49	72.9	43.26	42.65	42.65	2.5	9.1	11.6	53.3
50	67.27	45.15	43.33	43.33	1.8	8.3	10.1	52.4
Mean	**60.30**	**45.11**	**38.61**	**43.71**	**5.95**	**2.39**	**8.35**	**37.08**
Max.	**78.11**	**60.18**	**71.4**	**86.2**	**11.2**	**4.6**	**15.3**	**70.9**
Min.	**43.73**	**34.26**	**29.95**	**27.1**	**2.7**	**0.8**	**3.9**	**16.3**
Range	**34.38**	**25.92**	**41.45**	**59.1**	**8.5**	**3.8**	**11.4**	**54.6**
SD	**8.99**	**6.15**	**6.90**	**16.01**	**2.29**	**0.95**	**3.00**	**15.52**
CV %	**14.90**	**13.63**	**17.87**	**36.72**	**38.55**	**39.89**	**35.97**	**0.41**

D) Bulk density of matured Nutmeg fruit (Variety- *Konkan Vishwashri*)

Sr. No.	Wt. of empty box, g	Wt. of box + Sample, g	Wt. of sample, g	Volume of box, cm^3	Bulk density, g/cm^3
1.	85	1637	1552	2783	0.55
2.		1743	1658		0.59
3.		1692	1607		0.57
4.		1749	1664		0.59
5.		1793	1708		0.61
Mean					0.58
SD					0.02
CV %					3.65

APPENDIX III

A) Fruit Detachment Force(FDF) andFDF/Weight Ratio of matured fruit Cv-Konkan Vishwashri

Sr. No.	FDF of Matured fruit, kg	Weight of the matured fruit, g	Matured FDF/W ratio, kg/g
1	0.90	42.81	0.021
2	1.37	56.59	0.024
3	1.90	58.33	0.032
4	0.65	55.21	0.011
5	1.32	58.83	0.022
6	1.20	59.16	0.020
7	1.50	54.01	0.027
8	1.20	106.50	0.011
9	1.39	109.92	0.012
10	2.35	104.48	0.022
11	1.45	79.69	0.018
12	1.70	82.12	0.020
13	1.35	86.29	0.015
14	1.42	56.90	0.024
15	1.75	73.39	0.023
16	1.56	54.15	0.028
17	0.70	60.10	0.011
18	1.58	81.11	0.019
19	1.70	96.68	0.017
20	0.97	60.21	0.016
Mean	**1.39**	**71.82**	**0.019**
Max.	**2.35**	**109.92**	**0.32**
Min.	**0.65**	**42.81**	**0.011**
Range	**1.7**	**67.11**	**0.021**
SD	**0.40**	**20.24**	**0.006**
CV %	**29.06**	**28.18**	**31.05**

B) Fruit Detachment Force (FDF) and FDF/Weight Ratio of unmatured fruit Cv- Konkan Vishwashri

Sr.No.	FDF of unmatured fruit, kg	Weight of unmatured fruit, g	Unmatured FDF/W ratio, kg/g
1	0.97	40	0.024
2	1.32	38	0.034
3	1.55	49	0.031
4	1.20	42	0.028
5	1.77	50	0.035
6	1.92	67	0.028
7	1.39	48	0.028
8	1.03	51	0.020
9	1.29	52	0.024
10	1.38	43	0.032
11	1.19	45	0.026
12	1.72	54	0.031
13	1.89	39	0.048
14	1.68	52	0.032
15	1.17	44	0.026
16	1.34	30	0.044
17	1.12	55	0.020
18	1.28	62	0.020
19	1.42	42	0.033
20	1.18	46	0.025
Mean	**1.39**	**47.45**	**0.03**
Max	**1.92**	**67**	**0.048**
Min	**0.97**	**30**	**0.02**
Range	**0.95**	**37**	**0.028**
SD	**0.27**	**8.51**	**0.007**
CV, %	**19.42**	**17.93**	**24.78**

APPENDIX IV

A) Anthropometric Data of Agricultural Male Workers from Konkan Region for design consideration of manual nutmeg harvesting system

Parameters	Mean	S.D	Minima	Maxima	5th Percentile	95th Percentile
Weight, kg	51.9	8.5	30.0	87.0	37.9	65.9
Vertical reach, cm	209.1	8.6	181.1	237.1	195.0	223.2
Vertical grip reach, cm	197.5	8.4	171.0	288.0	183.7	211.4
Stature, cm	163.9	6.5	144.7	195.1	153.2	174.6

B) Details of selected male subjects for operating newly developed harvestingsystem

Sr. No	Name	Code	Age, years	Weight, kg	Stature, cm	HR max, bpm
1	Sujit Yamagar	A	24	48	163	196
2	Omkar Nagwade	B	20	53	160	200
3	Mahesh Bichkule	C	24	60	172	196
4	Vicky Waghmare	D	24	60	165	196
5	Sandip Rupnar	E	22	59	164	198
6	Suraj Devkar	F	21	63	173	199
Mean			**22.5**	**57.16**	**166.16**	**197.5**
SD			**(±1.76)**	**(±5.56)**	**(±5.19)**	**(±1.76)**

C) Maximum aerobic capacity (VO2 max) of selected male subjects for operating newly developed harvesting system

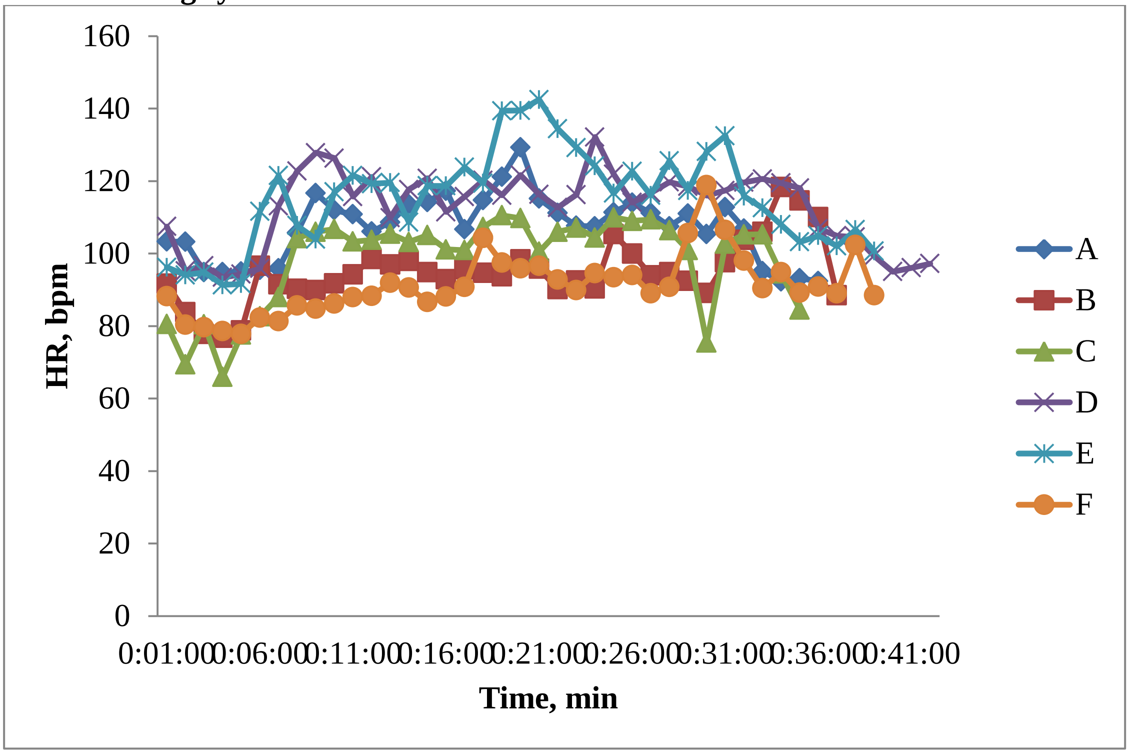
Subjects	**Subject code**	**Maximum heart rate, Bpm**	**Maximum aerobic capacity (VO2 max), l/min**
1	A	196	1.28
2	B	200	2.75
3	C	196	3.38
4	D	196	2.77
5	E	198	1.85
6	F	199	2.00
Mean		**197.5**	**2.33**
SD		**(±1.76)**	**(±0.76)**

D) Subject's heart rate during harvesting operation by developed manual Nutmeg harvesting system

Sr. No.	Time	A	B	C	D	E	F
1	1.00	103.38	91.69	80.53	107.46	96.23	88.23
2	2.00	103.25	83.83	69.41	95.25	94.08	80.42
3	3.00	94.83	77.83	80.5	96.66	94.83	79.67
4	4.00	94.83	76.75	66	93.41	91.33	78.58
5	5.00	95	78.83	77.66	94.33	91.66	77.83
6	6.00	95.5	96.66	82.66	95.91	111.67	82.33
7	7.00	95.91	91.5	88	113.17	121.5	81.33
8	8.00	105.75	90.25	104.25	122.75	107.75	85.67
9	9.00	116.67	89.91	106	127.83	104	84.83
10	10.00	112	91.75	106.75	126.33	117	86.17
11	11.00	110.83	94.25	103.33	115.75	121.58	88
12	12.00	106.08	98.5	103.75	121.17	119.25	88.33
13	13.00	108.67	97	105.5	109.92	119.58	91.92
14	14.00	113.58	98	103.17	117.67	108.67	90.67
15	15.00	114.25	94.83	105.08	120.75	118.67	86.67
16	16.00	117.33	92.91	101.17	111.5	118.67	88.17
17	17.00	106.67	95.66	100.92	115.75	123.83	90.83
18	18.00	114.75	94.66	107.33	120.25	119.42	104.3
19	19.00	121.17	93.75	110.58	116.08	139.42	97.5
20	20.00	129.33	98.41	109.75	121.67	139.5	95.92
21	21.00	115.17	95.83	100.5	116.33	142.5	96.67
22	22.00	111.17	90.17	106	112.75	134.42	92.83
23	23.00	107.67	92.58	107.17	116.25	129.25	89.92
24	24.00	107.5	90.33	104.42	132.17	124.17	94.58
25	25.00	111.42	105.42	110	121.92	116.67	93.42
26	26.00	114	100	109	114.08	122.67	94.08
27	27.00	111.17	94	109.42	116.75	116.08	89.08
28	28.00	107.5	94.833	106.42	119.75	125.58	90.83
29	29.00	111	92.5	100.92	118.5	117.42	105.6

30	30.00	105.42	89.083	75.417	116	128.17	118.9
31	31.00	112.83	97.583	102.75	117.42	132.5	106.5
32	32.00	106.92	103.75	105.25	119.67	115.83	98.08
33	33.00	95.167	106	105.33	120.58	112.58	90.42
34	34.00	92.333	118.33	94.5	119.5	108	94.83
35	35.00	93.16	114.67	84.5	118.08	103.25	89.17
36	36.00	92.41	110.08		106.92	104.92	90.92
37	37.00		88.5		104.92	102.08	89.08
38	38.00				104.58	106.58	102.4
39	39.00				99.33	100.67	88.5
40	40.00				95		
41	41.00				96.08		
42	42.00				97.25		
Resting HR		**98.25**	**81.78**	**74.82**	**97.42**	**93.62**	**80.94**
Working HR		**111.07**	**94.62**	**103.31**	**117.79**	**121.87**	**90.50**
ΔHR		**11.81**	**12.83**	**28.49**	**20.37**	**28.24**	**9.55**

E) Heart rate response of subjects during operating developed manual Nutmeg harvesting system



F) Body part discomfort score (BPDS) of male subject while operating existing manual Nutmeg harvesting system

Category	Weightage	Body part experiencing pain						Score					
		A	**B**	**C**	**D**	**E**	**F**	**A**	**B**	**C**	**D**	**E**	**F**
I	6	2,3	2,3	-	-	-	-	12	12	-	-	-	-
II	4	6,7	4,5	6,7	4,5	4,5	6,7	8	8	8	8	8	8
III	2	12,13	7	12,13	10,11	12,13	10,11	4	2	4	4	4	4
	Total							**24**	**22**	**12**	**12**	**12**	**12**
	Mean							**15.67**					

APPENDIX V

A) **Specification of computerized tread mill (COSMED S.r.I)** (Model No. T150)

Sr. No	**Particulars**		**Value**
I	**Dimensions**		
	1.	Running surface length, cm	150
	2.	Width, cm	50
	3.	Weight, Kg	190
II	**Performance**		
	1.	Speed, kmph	0-22
	2.	Elevation Range, %	0-25%
	3.	Maximum elevation, degree	14
	4.	Maximum Patient Weight, kg	200
	5.	Special Speed, kmph	0-60
III	**Protocols**		
	1.	Acceleration levels	7
	2.	Exercise profile	6
	3.	Definable profile	8
	4.	Test profile	28
IV	**Hardware**		
	1.	Motor System	1 phase
	2.	Motor Capacity, kW	3.3
	3.	Motor Voltage, V	230

A) Specifications of energy measurement system (K5b2) (Serial No. 2016050165)

Sr. No.		Particulars	Specifications
I	**Portable Unit**		
	1.	Memory, breaths	16,000
	2.	Display LCD	2 lines x 16 characters
	3.	Serial Port	RS 232C
	4.	Power supply	Ni-MH rechargeable batteries
	5.	Thermometer	0-500C
	6.	Barometer, kPa	53-106
	7.	Dimensions portable unit, mm	170 ×55 × 100
	8.	Dimensions battery, mm	120 × 20 × 80
	9.	Weight, g	400
II	**Receiver Unit**		
	1.	Battery, V (AC)	4 × 1.5
	2.	Dimensions, mm	170 × 48 ×90
	3.	Weight, g	550
	4.	PC interface	RS 232
III	**Battery charger Unit**		
	1.	Power supply, V	120 – 240
	2.	Power consumption, w	25
IV	**Flow meter**		
	1.	Type	Bidirectional digital turbine Φ 28 mm
	2.	Flow Range, l/sec	0,03 – 20
	3.	Accuracy, %	± 2
V	**Oxygen Sensor (O2)**		
	1.	Response time, ms	< 150
	2.	Range, % O2	7 – 24
	3.	Accuracy, % O2	± 0.02
VI	**Carbon Dioxide Sensor (CO2)**		
	1.	Response time, ms	< 150
	2.	Range, %	0 – 8
	3.	Accuracy, %	± 0.01
VII	**Power Supply**		
	1.	Voltage, v	100 – 240

B) Specifications of computerized polar heart rate monitor
(Model No - Polar RS 400^{Tm}, China)

Sr. No.	Particulars		Specifications
I	**Transmitter**		
	1.	Battery life of wear link	Avg. 2 years (3 h/day, 7 days/week)
	2.	Battery type	CR 2025
	3.	Operating temperature, ^{0}C	-10 to + 40
	4.	Connector material	Polyamide
	5.	Strap material	Polyurethane/ Polyamide
II	**Wrist unit (class one laser product) (Polar 331)**		
	1.	Battery life	Avg.1 year (1 h/day, 7 days/week)
	2.	Battery type	CR 2032
	3.	Operating temperature, ^{0}C	-10 to + 50
	4.	Watch accuracy	Better than ± 0.5 sec/day at 25^{0}C
	5.	Accuracy of heart rate	± 1% or 1 bpm, whichever larger
	6.	Heart rate measuring range, bpm	15-240

APPENDIX VI

1. Cost of operation by straight line method for the Newly developed manual Nutmeg harvesting system

Sr. No.	Particulars					Value
1.	The cost of developed harvesting system, Rs					8,082
	Material	Quantity, Nos.	Weight, kg	Rate, Rs	Amount, Rs	
	Harvesting platform (material- aluminum)	1	22	220	4,840	
	Telescopic pole (diameter 20 mm and 16 mm, total length- 4000 mm material- aluminum)	1	1.25	1050	1,050	
	Fruit harvester (material MS rod dimensions- 8 mm diameter and 650 mm length)	1	0.5		32	
	Fruit collecting bascket (materials- MS road dimensions- 8 mmdiameter and 1200 mm length)	1	0.750		60	
	Total material cost, Rs				5,982	
	Fabrication cost, Rs				2,100	
	Total cost, Rs				8,082	
2.	Useful life, years					5
3.	Working hours per year					240
4.	Salvage value (10% of initial cost)					808.2
5.	Repair and maintenance (10 % of initial cost), /h					808.2
6.	Wages of operator per day of 8 hour, Rs					300

Total cost = Material cost + Fabrication cost

= 5,982 + 2,100

= 8,082 Rs

Determination of cost of operation per hour

Unit cost of machine

1.	Cost of machine, Rs (C)	8,082/-
2.	Working life of machine, year (L)	5
3.	Annual use, h/yr (H)	240 (4 x 30 x 2)
4.	Salvage value, (S)	10 % of initial cost
5.	Annual interest of investment	@ 5 %.
6.	housing, (Rs)	@ 1.5 %.
7.	Repair and maintenance, (Rs/h)	10 % of initial cost

Calculation:

(A) Fixed cost

1. Depreciation (D)/h =(C-S)/(L×H) =(8,082-808.2)/(5×240) =6.0615/-
2. Interest (I) =[(C+S)/2]×[i/H] =$\frac{8,082+808.2}{2} \times \frac{5}{100\times240}$ =0.9260/-

   Where,

   C= Initial Cost, Rs

   S= Salvage Value, Rs

   L= Useful life, yr

   i= Rate of interest, % and

   H=Working hours per year
3. Housing (Rs/h) =1.5 % of Initial cost =Housing cost/h

   =$\frac{8082\times1.5}{100\times240}$ =0.5051/-

Total fixed cost =6.0615+ 0.9260+ 0.5051 =7.4926 Rs

(B) Variable cost

1. Operator cost (Rs/h) =$\frac{\text{Wages of operator}}{\text{working hours}}$ =300/8 =37.5/-
2. Repair and maintenance (Rs/h) =10 % of initial cost =$\frac{8082\times10}{(100\times240)}$ =3.3675/-
3. Total variable cost = 37.5 + 3.3675 =40.8675 Rs/h

(C) Operating cost

= Total fixed cost + Total variable cost =7.49+40.8675

= 48.35 Rs/h

2. Economics of hook method and beating of fruits by bamboo stick

A. Fixed cost

In hook and beating of Nutmeg fruits harvesting system there was no mechanical mechanism or any other material used therefore,

Total fixed cost = 00.00

B. Variable cost

1. Operator cost (Rs/h) =(Wages of operator)/(working hours)

   $=(300 \times 2)/8$

   $=600/8$

   =75/-

2. Repair and maintenance (Rs/h) = 00.00
3. Total variable cost = $75.00 + 00.00$

   = 75.00 Rs/h

C. Operating cost

$= \text{Total fixed cost} + \text{Total variable cost}$

$= 00.00 + 75.00$

= 75.00 Rs/h

APPENDIX VII

I. Field performance of newly developed Nutmeg harvesting system (trial I)

Subject/ farmer code	Fruit harvesting without platform		Fruit harvesting with platform		Total harvested fruits		Harvesting time, h	Time loss, h	Total harvesting time, h
	kg	Nos.	Kg	Nos.	kg	Nos.			
A	5.25	91	16.02	286	21.27	377	1.33	0.84	2.17
B	6.78	109	16.42	319	23.2	428	1.49	0.68	2.17
C	4.65	80	9.14	211	13.80	291	1.48	0.76	2.24
Sum	16.66	280	41.58	816	58.27	1096	4.3	2.28	6.58
Mean	5.56	93.33	13.86	272	19.42	365.33	1.43	0.76	2.19

II. Field performance of newly developed Nutmeg harvesting system (trial II)

Subject / farmer code	Fruit harvesting without platform		Fruit harvesting with platform		Total harvested fruits		Harvesting time, h	Time loss, h	Total harvesting time, h
	kg	Nos.	kg	Nos.	kg	Nos.			
D	3.4	51	11.70	192	15.11	243	1.3	0.76	2.06
E	3.49	59	9.98	170	13.48	229	1.09	0.58	1.67
F	2.97	60	13.50	248	16.47	308	1.49	0.69	2.18
Sum	9.86	170	35.18	610	45.06	780	3.88	2.03	5.91
Mean	3.28	56.66	11.72	203.33	15.02	260	1.29	0.67	1.97

III. Field performance of newly developed Nutmeg harvesting system (trial III)

Subject / farmer code	Fruit harvesting without platform		Fruit harvesting with platform		Total harvested fruits		Harvesting time, h	Time loss, h	Total harvesting time, h
	kg	Nos.	kg	Nos.	kg	Nos.			
G	8.91	141	50.9	802	59.81	943	5.87	1	6.87
H	3.84	60	5.74	122	9.58	182	1.03	0.34	1.37
I	4.78	91	9.86	165	14.65	256	1.73	0.56	2.29
Sum	17.53	292	66.5	1089	84.04	1381	8.63	1.9	10.53
Mean	5.84	97.33	22.16	363	28.01	460.33	2.87	0.63	3.51

IV. Damage fruit per cent of harvested fruits by newly developed manual Nutmeg harvesting system (trial I)

Subject / farmer code	Total harvested fruits, Nos.	Damaged fruit fall during harvesting without platform, Nos.	Damaged fruit fall during harvesting with platform, Nos.	Total damaged fruit, Nos.
A	377	2	3	5
B	428	3	2	5
C	291	2	2	4
Sum	1096	7	7	14
Mean	365.33	2.33	2.33	4.66

V. Damage fruit per cent of harvested fruits by newly developed manual Nutmeg harvesting system (trial II)

Subject / farmer	Total harvested fruits,	Damaged fruit fall during harvesting without platform, Nos.	Damaged fruit fall during harvesting with platform, Nos.	Total damaged fruit, Nos.

code	Nos.			
D	243	2	2	4
E	229	3	3	6
F	308	0	4	4
Sum	780	5	9	14
Mean	260	1.66	3	4.66

VI. Damage fruit per cent of harvested fruits by newly developed manual Nutmeg harvesting system (trial III)

Subject / farmer code	Total harvested fruits, Nos.	Damaged fruit fall during harvesting without platform, Nos.	Damaged fruit fall during harvesting with platform, Nos.	Total damaged fruit, Nos.
G	943	5	2	7
H	182	2	2	4
I	256	0	2	2
Sum	1381	7	6	13
Mean	460.33	2.33	2	4.33