Design Analysis of a Manual Cassava Harvesting Tool

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PROJECT REPORT

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DECLARATION

We hereby declare that this project report entitled **"Design Analysis of a Manual Cassava Harvesting Tool"** is a bonafide record of project work done by us during the course of project and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

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CERTIFICATE

Certified that this project work entitled **"Design Analysis of a Manual Cassava Harvesting Tool"** is a record of project work done jointly by **OMNARAYAN** and **SWAPNESH PATEL** under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship or other similar title of another University or Society.

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SYMBOLS AND ABBREVIATIONS

Symbols		Abbreviations
/	:	Per
%	:	Percentage
2D	:	2-Dimensional
3D	:	3-Dimensional
CAD	:	Computer aided design
CAE	:	Computer aided engineering
CDS	:	Conical drum seeder
cm	:	Centimetre(s)
cm^2	:	Square centimetre(s)
cm^3	:	Cubic centimetre(s)
DS	:	Direct seeding
et al.	:	And others
Fig.	:	Figure
g	:	Gram(s)
ha	:	Hectare
ha/h	:	Hectare per hour
kg	:	Kilograms
kg/m^3	:	Kilogram per cubic meter
km/hr	:	Kilometre per hour
l	:	Litre(s)
m	:	Meter(s)
m/s	:	Meter per second
MB	:	Manual Broadcasting
mm	:	Millimetres
N	:	Newton
N-m	:	Newton meter
NO_2	:	Nitrogen dioxide
rpm	:	Revolution per minute

CHAPTER - I

INTRODUCTION

Cassava (Manihot esculenta) is the most widely cultivated root crop in tropics and is grown across a broad range of agro-climatic conditions. Tapioca is familiar crop which cultivated around Kerala and Tamil Nadu. It was harvested by using hand, it is very difficult to harvest crop so we decide to make harvesting machine which should be economical. Most of the Indian farmer's economic condition is not good, so they are not able to buy tractor or large harvesting machines, so manual harvesting tool helps them to harvest in low investment. It reduces the harvesting wages of farmers. Cassava is a shrub by, tropical, perennial plant that is less common in the temperate zone. There is shortage of skilled labour available for agricultural purpose. Because of this shortage the farmers have transitioned to use mechanical harvester. Manual harvesting of cassava root is labours involves drudgery and time consume. Large scale harvesters have harvesting attachments attached to the tractor. But it may damage the cassava, so the design is proposed to make a harvesting machine which will harvest the cassava without any damage and to make effective equipment available at nominal prices. This machine is cost effective and easy to maintain and repair for the farmer.

1.1. PRODUCTION OF CASSAVA

India acquires significant in the global tapioca scenario due to its highest productivity. About 90 percent of total tapioca cultivation area and production in India are confined in southern district of Tamil Nadu and Kerala. An average productivity of tapioca in this area is highest in the world. Globally, Cassava is grown in an area of 18.51 million ha with a production of 276.65 million tonne (FAO, 2012). India acquires significance in the global cassava scenario due to its highest productivity of 27.92 t/ha. It is cultivated in an area of 0.26 million ha in country with a production of 7.2 million tonne. Table 1.1. Shows data on area and production in different states during 2012-13. Cassava is cultivated eighty percentage in Tamil Nadu. It is majorly cultivated around Namakkal, Erode, Salem, Kanyakumari. It cultivates in 1.39 lakes hectares in Tamil Nadu. Most of the farmers are having below 2 hectares so they not using tractor for harvesting tapioca. They using daily wages peoples for harvesting it required more energy to harvest tapioca from field. Due to harvesting using daily wages people, wages for harvesting are accurse more it affects their profit. Existing model is an attachment which attached to tractor it images the tapioca root which affects its grade in market in order to overcome the problem a manual harvesting tool was design to harvest cassava root without bruises, thereby increases profit to farmer.

Table 1.1. Indian Production of Cassava in 2017-18 (Tonnes)

S. No.	State	Production	Share (%)
1.	Tamil Nadu	2,862.14	57.90
2.	Kerala	1,725.98	34.92
3.	Andhra Pradesh	192.15	3.89
4.	Nagaland	79.32	1.60
5.	Meghalaya	36.24	0.73
6.	Assam	28.87	0.58
7.	Karnataka	13.99	0.28
8.	Madhya Pradesh	4.29	0.09
9.	Arunachal Pradesh	0.08	0.00
	Total	**4,943.06**	

Source: National Horticulture Board (NHB)

Cassava is a perennial shrub which sometimes reaches the size of a small tree. The stems vary in colour from pale to dirty-white to brown marked by numerous nodes formed by scars left by fallen leaves. Pale to dark-green leaves is of fan shape with 5 to 9 lobes. Cassava is grown at different row to row and plant to plant spacing. The common spacing is 600 x 600 and 750 x 750 mm. These spacing of the crop result in spacing between the alternate rows of 1.2-1.5 m. A single root may weigh up to 4 kg under favourable conditions. The number of roots per plant varies from 2 to 7 with an average length of 275-435 mm and diameter of 45-75 mm at the time of harvest. Existing manual harvesting techniques lead to drudgery, wastage and also consume a lot of time and farm labour, which is scarce and costly. Cassava harvesting is still done manually in Ghana, Nigeria, Thailand and other parts of the world. Manual harvesting of cassava does not fit well with the modern processing factories. This is as a result of the low productivity associated with manual uprooting of cassava. The cost of manual harvesting is high; it is a tedious work and requires around 40 man-days/ha.

1.2. TECHNOLOGICAL DEVELOPMENT

Engineers at home and abroad have made many attempts towards the development of cassava uprooting devices. These include manual devices such as cut lasses and hoes and semi-mechanized devices such as Prairie mouldboard ploughs with different structural configurations such as:

- Inverting the whole ridge and roots with a mouldboard plough body.
- Pulling a mouldboard share (with the board removed) below the soil level.
- Using a mouldboard plough to split the ridge along the crest.
- Pulling specially designed blades to cut below the tubers.
- Using animal and tractor-drawn single disc ploughs to harvest tapioca.
- The combine harvester, or simply combine, is a machine that harvests tubers crops.

1.3. ERGONOMIC CONSIDERATION

Cassava harvesting is one of the tedious jobs. Back pain, shoulder pain, musculoskeletal injuries etc are the common ailments in the cassava harvesting workers. Different methods of cassava harvesting are used in different places. Average weight of cassava tuber bunch will be (5 to 20 kg) and in the case of hybrid variety it will go more than (25 to 35 kg). Therefore, the conventional type harvesting mentioned above causes drudgeries and workers face many types of musculoskeletal problems. Shoulder pain and back pain are the main problems which harvesting workers pointed throughout the survey of the harvesting operation and ant bite, insect bite, bees attack are the minor problems. As a result of these problems, the efficiency of work will reduce.

Keeping in view the above facts, the present study on **"Design Analysis of a Manual Cassava Harvesting Tool"** was undertaken with the following specific objectives.

i. To evaluate the existing practices of cassava harvesting with conventional methods.
ii. To develop a conceptualized design for ergo refined tool for reducing the drudgery in cassava harvesting.

CHAPTER - II

REVIEW OF LITERATURE

In this chapter, a brief review of work done relevant to different aspects of the problem under investigation is presented. Important literature on morphology of cassava tuber, various models of cassava root harvesting devices developed, physiological responses and rating of perceived exertion of subjects and biomechanical behaviour of the human body during harvesting operation are collected. The literatures collected are presented under the following main headings.

i. Morphology of cassava tuber
ii. Engineering properties of cassava
iii. Harvesting of cassava
iv. Ergonomics applied to harvesting operations

2.1. MORPHOLOGY OF CASSAVA TUBER

Figure 2.1 (a) and (b) show the morphology and transverse section of a cassava root tuber respectively. The roots are long depending on the type of variety, rough surface, and are all joint to the stem of the plant in the soil. Generally, the apex of the root tuber is large, followed by the middle portion whiles the bottom is the smallest in diameter. Never the less, the central core of the tuber in its transverse section shows the pith. Around the pith is the starchy flesh which comprises of the main part of the tuber. Usually, this portion is either white or cream and enclosed by a thin cambium layer. The peel of the tuber covers the cambium layer and it entails a corky periderm on the outward and cortex on the inward (Adetan *et al.*, 2003; Wickens & Onwueme,1979).

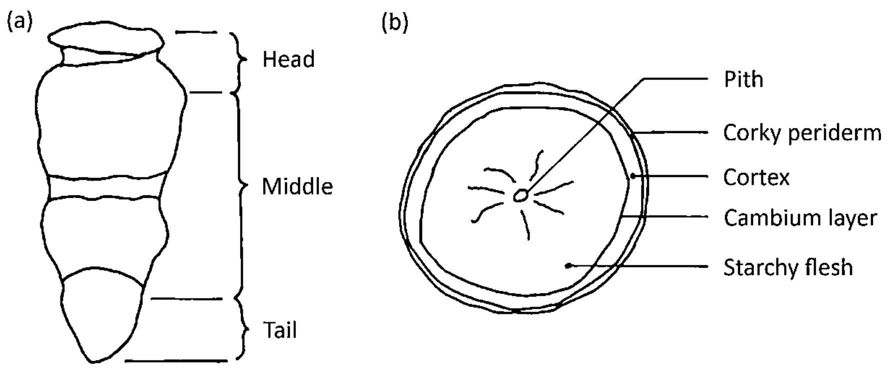


Figure 2.1: Morphology of Cassava: (a) Common Morphology (b) Transverse Section (Adetan et al., 2003)

2.2. ENGINEERING PROPERTIES OF CASSAVA

Mohsenin, (1986) reported that to design every machine the first step is to determine its engineering properties. These properties are beneficial in the design of equipment employed in the field of agricultural processing and farm machinery. The unit operations such as grading, drying, cleaning, storage, milling, handling, and transportation, thermal processing of foods are among the important operations in agricultural processing. In these operations, while handling of grains and other commodities, the properties that play an important role are physical, mechanical, frictional, rheological, aero and hydrodynamic, electrical and optical properties of the bio-materials. Information on these properties is of great importance for engineers, food scientists, and processors towards the efficient development of machines. For the sake of this article, the physio-mechanical properties are discussed.

2.2.1. PHYSICAL PROPERTIES

The knowledge of density and the specific gravity of cassava is needed in calculating the thermal diffusivity in heat transfer. These help to figure out Reynolds number in pneumatic and hydraulic handling of produce there by anticipating the structure and composition. Also, the shape, size, volume, area, color, and appearance of cassava are important in the analysis of the behavior of the production the handling of materials (Mohsenin,1986).

Designing components such as hoppers, chutes, screw conveyors, storage bins, pneumatic conveyors, the coefficient of friction, and angle of repose are determined. The sphericity of regular agricultural produce is between 0.32 and 1.00. Therefore, the lower the sphericity of the produce, the regular the produce. Since the sphericity of the cassava varieties tested were high ranging from 0.73-0.84. It is reported that cassava is irregular in shape. (Simonyan, 2015).

Subsequently, Adetan *et al.* (2003) showed that 0.106 to 0.215 makes the proportion of peel for the cassava tuber. The rest of the physical properties are shown in Table 2.1.

2.2.2. MECHANICAL PROPERTIES

Mechanical properties are defined as those that affect the behavior of the agricultural material under an applied force. The mechanical properties such as hardness, compressive strength, impact and shear resistance as shown in Table 2.1 affect a series of agricultural production. Data on these properties are useful for application in designing equipment for handling, milling, storage, transportation and food processing.

When the moisture content is lower, the tuber is harder and the ability to resists cutting and abrasion increases. This simply means that mechanical property depends on moisture content (Kolawole *et al.* 2007).

Oupathum *et al.* (2019) stated that the shearing stress and the specific shearing energy increase as the knife bevel angle increases from 20-40 degrees. Lomchangkum *et al.* (2020) also determined that the maximum cutting shear stress and force increased with increasing tuber age due to the increase in density and starch content.

Table 2.1. Physical and Mechanical Properties of Cassava tuber

Physical Properties	Mechanical Properties
Dimension: length, width, thickness & diameter	Hardness
Shape	Compressive strength
Weight	Compressive stress
Density	Shear strength
Porosity	Tensile strength
Volume	Coefficient of expansion
Surface area	Impact resistance
Angle of repose	Shear resistance
Specific gravity	Compressibility
Drag coefficient	Elasticity
Moisture Content	Cutting Force
Static coefficient of friction	Bending Strength
Sliding coefficient of friction	Deformation

2.3. HARVESTING OF CASSAVA

In reality, the difficult operation in cassava production is harvesting since it requires a lot of energy or man-power to harvest per plant. This is such that the highly perishable nature of the crop deteriorates as early as 1-3 days after harvest. It is therefore important to harvest cassava at the right time and in the proper manner (Agbetoye *et al.*, 2003). Harvesting of cassava is in three folds, thus manual, semi-manual and mechanized methods.

2.3.1. MANUAL HARVESTING

The manual method involves the hand where cutlass, hoe, mattock and other indigenous tools are used. This process is very difficult and is labour intensive when harvesting hectares of land. The stem of the cassava plant is cut slightly above the soil surface. Afterwards, the cassava root is uprooted from the soil by exerting force as shown in Plate 2.1 & 2.2 respectively. The cut stems reused for the next crop planting. (Mongkol *et al.*, 2007). According to Amponsah *et al.* (2018) approximately 23-47man h/ha is required for manual lifting of cassava with hands compared to the use of a hoe which requires between 42-51man h/ha. On moderately dry soils, manual harvesting tools are preferable while soils with moderately higher moisture content are best for manual uprooting techniques for cassava.

Plate 2.1. Manual Harvesting of Cassava with Cutlass, Hoe and Mattock

Plate 2.2. An Indigenous Cassava Lifter (Chalachai *et al.*, 2013)

2.3.2. SEMI-MANUAL HARVESTING

The semi-manual harvesting method employed the principle of lever and ensures that relatively less effort is needed to uproot the crop. The Council for Scientific and Industrial Research, Crop Research Institute (CSIR-CRI) Ghana, and the National Centre for Agricultural Mechanization (NCAM) Nigeria, designed a simple harvester as shown in Plate 2.3 and 2.4

respectively. With the advancement in technology, many of these harvesters are improved around the world.

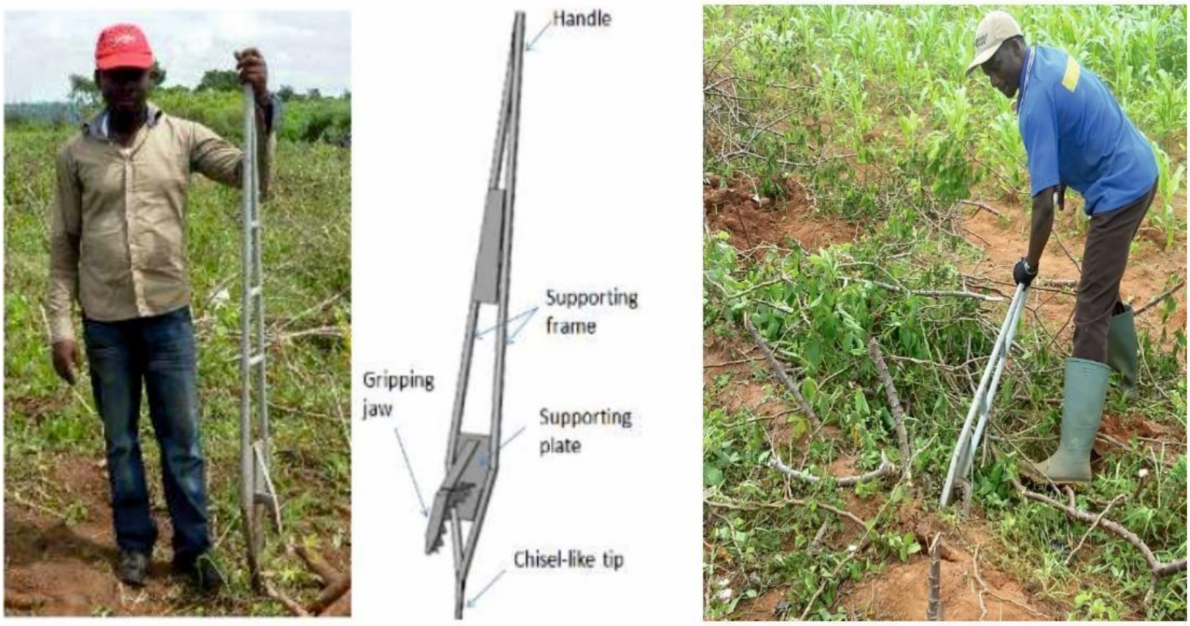


Plate2.3. Cassava Harvester designed by CRI (Shadrack *et al.*, 2017)

Plate 2.4. Cassava harvester designed by NCAM (Amponsah *et al.*, 2018)

2.3.3 MECHANIZED HARVESTING

These involve harvesting equipment hitched to a prime mover, often tractor, to uproot the crop. Nevertheless, in some cases, a little manual effort is still needed after the tuber is uprooted from the soil, especially the collection and separation of the tuber from the stem. The field is also required to be in good condition for optimum mechanical harvesting operations to be carried out (USDA,2003).

Mechanized harvesting of cassava is grouped in to two; semi-mechanized and fully mechanized methods. A side from digging of the cassava roots accomplished by the semi-mechanized method, the fully mechanized ones involve digging, uprooting, lifting of cassava roots to be transported by the conveyor.

i. Semi-mechanized Harvesters

Plate 2.5 and 2.6 show some of the cassava harvesters available in Thailand. They are grouped as fork blade and curve blade harvesters respectively. Fork blade harvester has the following advantages of not inverting the soil, it keeps the root for 2-3 days and the tractor does not break the root for the next row. The disadvantages of fork blade harvester are loss of more cassava roots in the soil, working width is too small and need powerful tractor to operate. However, curve blade harvester has the advantages such as, easy collection of the cassava roots, decrement in the loss of cassava roots in soil, can be used in a wide range of soil with a small tractor. The disadvantages of curve blade harvester are tractor damages the root for the next row, high root breaking loss and it needs more labour to collect the roots.

Plate 2.5. Fork Blade Harvester (Chalachai *et al.*, 2013)

Plate 2.6. Curve Blade Harvester (Chalachai *et al.,* 2013)

In Plate 2.7 it shows a mechanical harvester developed at the Leipzig University (LU), Germany. The cassava root is carefully loosened by the harvester and then lifted approximately 20 cm high. It is delivered to the transport unit made of two belts and a set of steel/plastic press rollers. The root clusters are detached with either hand or cutlass. It requires 55-80 kW and has a field capacity of about 0.25-0.38 (Bobobee *et al.,* 1994).

Plate 2.7. Mechanical Cassava Harvester designed by Leipzig University

Plate 2.8 shows the cassava harvester model P900 conducted by some researchers in Latin America and the Caribbean to help research and development for semi-mechanized cassava a harvester. The performance of the prototype harvester was tested and evaluated in Columbia. Besides, the harvester has a cutting disk that enabled deep penetration into the soil where manual harvesting is in to liable. To ease the process of harvesting, the stems of the plant should be cut off before harvesting to a height of 20-40 cm (Ospina *et al.,* 2002).

Plate 2.8. Cassava Harvester Model P900(Ospina *et al.*, 2002)

Plate 2.9, shows the mechanical harvester developed and manufactured in Ghana at the department of Agricultural & Biosystems Engineering, Kwame Nkrumah University of Science and Technology (KNUST). Its working depth ranges from 23-29 cm and has a field capacity of 0.4-0.52 ha/h (Amponsah *et al.*, 2018).

A – Beam to which digging unit is attached *B – Conical mouldboard*
C – Top link hitching point *D – Digger*
E - Vertical support *F – Lower link hitching points*
G – Slatted rods for shaking off soil

Plate 2.9. Mechanical Cassava Harvester designed by KNUST (Amponsah *et al.*, 2018)

ii. Fully Mechanized Harvesters

Thangdee, (2012) developed a cassava harvester and conveyor unit as shown in figure 2.2After the test and evaluation of the harvester, it has been demonstrated that such integration can address the problems in collecting and conveying cassava from the ground. The outcome of such research can be used for further development of appropriate mechanization. Based on the teste valuation, the harvester has a field capacity of 0.05 ha/h, 59.10% field efficiency and 3.23% loss caused by conveying the cassava root.

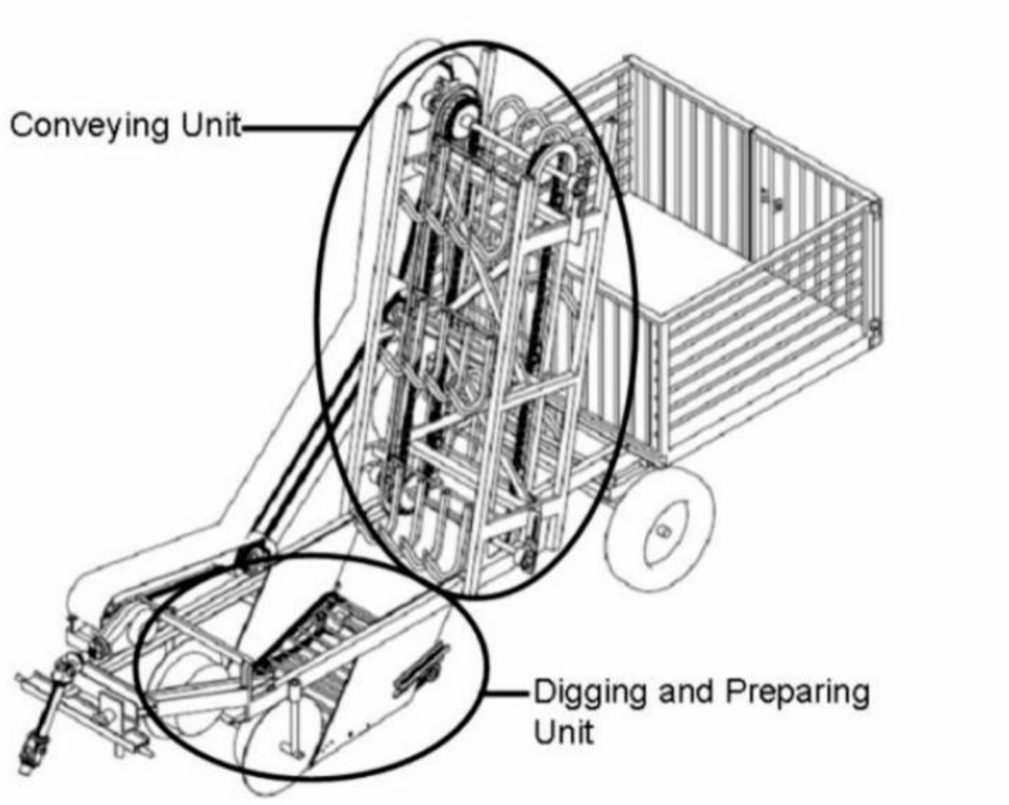


Figure 2.2. Fully mechanized harvester designed by (Thangdee, 2012)

Cassava Harvester by LU uses hydraulic system and its limitations are it requires human labour to detach the cassava root during harvesting. Model P900 Harvester has a shock absorber and cutting disk to facilitate harvesting. Its limitations are, there is no hydraulic system to facilitate the up and down movement of the harvester and requires extra labour to collect the cassava after harvest. Cassava Harvester by KNUST was a simple design that works better when crops are grown on ridges. Its limitations are, there is no hydraulic system and conveying unit. Cassava Harvester by Thangdee has a conveying unit that is operated by the PTO system of the tractor. Its limitations are, cutting of the stem of the plant must be done before harvesting the root crop.

2.4 ERGONOMICS APPLIED TO HARVESTING OPERATIONS

Ergonomic issues must be taken into account at the early design stage. Important human factors, such as vision, reach envelope, operator strength, and workloads determine to a large extent the product performance, and thus, need to be timely accessed during the product life cycle. Production agriculture workers suffer more from musculoskeletal disorders than any other type of injury or illness. Early studies related to the ergonomics and anthropometric considerations in tool designing are furnished here.

2.4.1. PHYSIOLOGICAL RESPONSE OF SUBJECTS

Work is any activity that calls for great physical exertion and is characterized by high energy consumption and serve stress on the heart and lungs. Energy consumption and cardiac effort set limits to the performance of heavy work and these two functions are often used to assess the severity of a physical task. Physiological cost involved in any operation is expressed in terms of cardio respiratory response of the subjects during work and the main parameters measured are heart rate and oxygen consumption rate. Heart rate integrates the total stress on the body and can be used as an index of the physiological cost of work. The physiological responses of the subjects assessed by researchers for various farming operations and the grading of energy cost of operation are furnished in Table 2.2.

Table 2.2. Physiological response of male subjects for agricultural tasks

S. No.	Operation	Energy cost of operation, $kJmin^{-1}$	Grading of energy cost	Source
i	Harvesting sugarcane with knife	25.5-26.3	Heavy	Thiyagarajan (2006)
ii	Conventional detrashing of sugarcane with hand	18.7	Moderately heavy	Thiyagarajan (2006)
iii	Detrashing sugarcane with tool	14.7	Moderately heavy	Thiyagarajan (2006)
iv	Weeding operation with finger type rotary weeder	26.7-29.9	Heavy	Thambidurai (2007)
v	Weeding operation with power weeder	22.8-27.4	Heavy	Thambidurai (2007)
vi	Traditional method of coconut tree climbing and harvesting	35.1	Very heavy	Mohankumar (2009)
vii	Coconut tree climbing and harvesting with tree climbing device	25.1	Heavy	Mohankumar (2009)
viii	Tea pruning with knife	29.9	Very heavy	Anon. (2009)
ix	Tea pruning with powered brush cutters	24.8-26.2	Heavy	Anon. (2009)
x	Traditional method of arecanut stripping	26.7	Heavy	Anon. (2009)
xi	Arecanut stripping with mechanical stripper	22.3	Moderately Heavy	Anon. (2009)
xii	Traditional method of areca tree climbing and harvesting bunches	33.8	Very heavy	Anon. (2009)

Sen (1969) tentatively classified the manual jobs based on the physiological responses of young Indian male and female workers. The tentative classification of strains in different types of jobs is furnished in table 2.3.

Table 2.3. Classification of workload for male subjects

Physiological workload	Physiological Variables		
	Heart rate (Beats/min)	Oxygen consumption (l/min)	Energy expenditure (kCal/min)
Very light	<75	< 0.35	< 1.75
Light	75 - 100	0.35 – 0.70	1.75 – 3.5
Moderately heavy	100 - 125	0.70 – 1.05	3.5 – 5.25
Heavy	125 - 150	1.05 – 1.40	5.25 – 7.00
Very heavy	150 - 175	1.40 – 1.75	7.00 – 8.75
Extremely heavy	Above 175	>1.75	> 8.75

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

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

$$E = 0.068 \times PHR - 4.59 \qquad \text{------- (2.2)}$$

where,

E is Energy expenditure in kCal/min.

PHR is Peak heart rate in beats/min.

Saha (1976) obtained a highly satisfactory linear relationship between energy expenditure and working heart rate from data of field studies. He also derived a regression equation for predicting energy expenditure of men of 58 kg body weight from working heart rate.

$$E\ (kCal\ min^{-1}) = 0.0695\ PHR\ (beats\ min^{-1}) - 4.332 \qquad \text{------ (2.3)}$$

Nag *et al.* (1980) categorized the occupational work load in performing the agricultural activities. Work intensity of the agricultural operations were classified in terms of ‘light’ ‘moderate’ ‘heavy’ and ‘extremely heavy’ which corresponded up to 25 per cent, 25-50 per cent, 50-75 per cent and above 75 per cent of the maximal oxygen uptake respectively, obtained from rhythmic bicycle ergometry. Average energy expenditure rate obtained over the working hours was 11.11 kg/min or about 28 per cent of VO_2 max. It was suggested that the workers might be allowed to work up to the limit of 40 per cent VO_2 max, for longer duration, if an increase in productivity was desired. He also suggested that for long duration work the activity levels should not exceed 35 to 50 per cent of VO_2 max, in excess of which a substantial amount of anaerobiosis occurred in the working muscles.

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

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

Susheela *et al*. (2001) calculated the occupational workload of female agricultural workers in performance of selected agricultural activities like picking of stalks and stubbles, sowing, transplanting, inter culturing, weeding and harvesting of wheat and jowar crop. They found that the mean heart rates were 101.0±7.0, 118.6±15.1, 131.0±7.0, 109.1±7.1, 126.0±7.0 and 123.0±5.0 beats min^{-1} respectively for selected agricultural activities. The physiological workload of inter culturing, harvesting of wheat and jowar were classified as “heavy”.

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

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

2.4.2. ACCIDENTS AND DRUDGERY INVOLVED AGRICULTURAL ACTIVITIES

According to the AICRP data on the ergonomic evaluation of hand tool and its accidents of Indian agricultural workers, (AICRP work shop on Ergonomics and safety in agriculture, CIAE Bhopal) the overall incidence rate of hand tools related injuries varied from 0.02 (Northern India) to 0.42 per cent (Southern India) per 1,000 hand tools per yr. Taking data from central India, the incidence rate for sickles was 0.16 per cent, followed by pickaxes as 0.09 per cent per 1000 tools per year. The sickle related injuries mostly occurred while harvesting hard-stem crops like pigeon pea, chickpea, mustard and sorghum, and low-back injuries have been reported for pickaxes (Anonymous, 2000).

The activities like weeding, cutting/uprooting, picking/diffing, transplanting, removing of stalks and stubbles, threshing was found to be maximum drudgery involved agricultural activities performed by the women, (Anonymous, 2001).

Nag and Nag (2004) conducted a review on drudgery, accidents and injuries in Indian Agriculture. He pointed out that the accidents and injuries were natural hazards to everyone working in the farm environment and these happened as a culmination of multiple factors, e.g., man, machine, crop and toxic chemicals or environmental factors.

Kumar *et al.* (2006) conducted a study on ergonomic evaluation of hand tools injuries among Indian farmers. This study reported that the mechanism of injuries was slippage of tool from hand or hitting a hard surface in impact type soil interactive tools (spade). In the case of harvesting tools (sickle), amputations of fingers and in weeding fork abrasions on underside of little finger because of ground contact were common injuries. In case of axe and sugar cane cutter injuries, higher severity injuries were sustained on upper extremities.

2.4.3. ANTHROPOMETRIC DATA IN THE DESIGN OF FARM TOOLS

Pheasant and O'Neill (1975) investigated on the handle design in a gripping and turning task. They reported that the strength was deteriorated when handles greater than 5 cm in diameter were used and for reduction of the abrasion of the skin and hand-handle contact should be maximized. The size of the handle rather than its shape was most important for forceful activities. Cylindrical handles are better than handles with finger grooves. Handle lengths should be at least 11.5 cm plus clearance for large hands. An extra 2.5 cm should be added if gloves need to be allowed.

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

Kanchan *et al.* (2010) analysed the anthropometrical relationships within and between hand and foot dimensions. The study was conducted on 240 Rajput (120 males and 120 females) from North India. The results showed a significant correlation between and within the dimensions of hands and feet. Multiplication factors, linear and multiple regression models were derived to reconstruct the hand and foot even when a single dimension is available from the extremities.

Yadav *et al.* (2010) presented a compilation of strength parameter data of male and female workers of Saurashtra region that could be used as a guide for designing and modifying agricultural and industrial equipment suiting to human strength capabilities and limitations. The average push strength for male and female workers (with both hands in standing posture) was found to be 248.2 and 171.0 N respectively whereas the pull strength in standing posture was 232.3 and 141.7 N respectively. These strength parameters were found to play significant role in design of manually operated push-pull type equipment. The right-hand push and pull strength for male and female agricultural workers were within the range of 49.7 to 96.5 N which prominently assist in the design of joystick, gear shift lever and handle lever.

2.5. ENERGY REQUIREMENT IN DIFFERENT AGRICULTURAL OPERATION

Chancellor (1958) stated that when slicing with a knife, friction caused the fibres or parts of fibres to adhere to the knife-edge. As the movement continued, the fibres became separated from the rest of the stem in the region of the knife but were still attached. As the fibres were further separated, they were stressed in pure tension and hence fail. This process took more energy but could be achieved using smaller forces since only a few fibres were involved at any one time.

Das and Gupta (1972) used an apparatus consisting of a cutting blade attached to a rigid pendulum arm that swung in a vertical plane to cut cane specimens located vertically below the pendulum's fulcrum. They observed the influences of the edge angle, oblique angle, tilt angle, blade velocity and effective stubble height on cutting resistance and cutting energy. They arrived at the following conclusions:

i. The minimum cutting force and energy occurred at an edge angle of about 25^0.

ii. Both the cutting force and energy decreased with increase in oblique angle.

iii. Cutting energy was greater with increasing knife velocity, but the effect of velocity on cutting resistance was not significant.

iv. The influence of the tilt angle on cutting resistance was not significant but both cutting resistance and cutting energy were minimum at a tilt angle of about 20^0.

v. Cutting energy decreased with greater effective stubble height.

vi. Both cutting resistance and cutting energy were found to increase with stalk diameter.

Akritid (1974) reported that the change of the angle of inclination of the blade had the greatest influence on the consumed energy. The age of the plant constituted another important factor that influenced the energy consumption. A change of the coefficient of friction did not influence seriously the amount of the consumed energy. Within the range of blade weight used in these experiments, the energy consumed was not influenced by the mass of the blade where the impact velocity was varied over a range of 7.0 to 11.5 m/s.

Prasad and Guptha (1975) reported that the cutting energy and maximum cutting force were directly proportional to the cross-sectional area and inversely proportional to the moisture content of the stalk. The ultimate shear strength, shear energy and ultimate compressive strength in the transverse direction and modulus of toughness were determined by a table model INSTRON testing machine and observed to decrease with increase in rate of deformation. A pendulum type impact shear test apparatus was used to determine the cutting energy requirement of the stalk. They found the optimum values of knife bevel angle of 23^0, knife approach angle of 32^0, shear angle of about 55^0 and the knife velocity of about 2.65 m/s.

McRandal and McNulty (1978) investigated the impact cutting behaviour of forge crops theoretically and experimentally. Laboratory tests revealed that energy consumption in cutting groups of grass and oat straw stems decreased by approximately 25 per cent as blade velocity increased from 20 to 60 m/s. The minimum cutting velocity for both grass and oat straw was approximately 20 m/s which confirmed theoretical predictions arising from models of the forage stem as a beam or as a particle.

McRandal and McNulty (1978) tested impact cutting behaviour of forage crops in field condition. Mowing tests at a blade velocity of 78.1 m/s and a forward velocity of 5.5 km/h revealed that power consumption increased linearly as crop density increased from 0.95 to 5.42 kg/m^2. Energy balances as a function of both cutting and forward velocities revealed that crop acceleration and conveyance normally consumed more than 50 per cent of total energy at the mower rotor shaft while energy consumed in shearing stems was normally less than 3 per cent.

Singh and Singh (1978) conducted a study on force requirements of different sickles. The performance of different hand sickles was evaluated by finding the requirement in harvesting wheat, paddy, maize and jowar crops. The variables studied were shape, surface and material of sickle. Five shapes, two surfaces and four materials were selected for the study. Tests indicated that the sickle having shapes as per I.S.I. standards, require minimum force followed by Japanese type sickle. No significant effect of metal was found on force requirement. Sickles with serrated surface gave better performance than plain surface in general.

O'dogherty and Gale (1986) studied the cutting of grass stems in laboratory. The results showed that, at critical cutting speed of 15 to 30 m/s, below which cutting became progressively more inefficient in terms of specific cutting energy. Relatively low energies were recorded at 5 to 10 m/s when stems remained uncut. The double shear blade arrangement was the most effective. Sharp blades required about 1/3 of the specific energy and peak force at speeds below the blunt blades. Increasing rake angle reduced specific energy and peak force at speeds below the critical value. For stems rigidly clamped at the top, the specific cutting energy was markedly reduced. Study showed that highly inclined stems (at 70° to the vertical) required critical speeds greater than 40 m/s.

O'dogherty and Gale (1991) studied the effect of blade parameters and stem configuration on the dynamics of cutting grass in laboratory. Author concluded that, the blade rake angle was found with no significant effect on specific cutting force or energy when cutting above the critical speed. At lower speeds, however, increasing the blade angle resulted in an increasing number of uncut stems. The bluntest blade (0–15 mm edge radius) required three times the specific cutting energy and twice the specific peak force as a sharp blade (0–325 mm edge radius). The principal effect of the angle of stem inclination was an increase in critical speed from 25 to 60 m/s, as the angle of inclination increased from 0 to 60°.

Geoff and shlomowitz (1992) investigated on different types of hand tools of various designs, sizes and shapes are used for cane harvesting. Sugarcane harvesting manually by traditional tools was a highly labour intensive and costly operation.

Visvanathan *et al.* (1996) conducted experiment to determine the optimum values of cutting velocity, knife bevel angle and shear angle (angle of cut with respect to the longitudinal axis of the tuber) on the energy required to cut the tubers by using pendulum impact tester. Results suggested that the specific cutting energy of the tuber (cutting energy per unit area of cut) was minimum for cutting velocities in the region of 2.5 m/s, shear angles of 60° to 75° and bevel angles of 30° to 45°.

Jelani *et al.* (1999) investigated the effect of cutting angle and frond maturity on the specific reaction force and energy requirement for cutting oil palm fronds. A spring powered sickle cutter was used in this experiment. The experiment conducted was to determine the magnitude of reaction force that would be transferred to the harvester in the cutting operation. He concluded that only the cutting angle significantly affected the specific reaction force and energy. The ratio of reaction force to the maximum cutting force (R/Fc_{max}) was also studied. The ratio gives the percentage of cutting force being transferred to the harvester during the cutting process. It was found that R/Fc_{max} was significantly affected by the cutting angle and frond maturity

Chattopadhyay and Pandey (1999) determined shear, compression and bending properties of sorghum (*S. bicolor*) stalks by using a universal testing machine. The stalk specimens were deformed in a quasi-static process using knives with 30^0 to70^0 bevel angles at a rate of loading from 10 to 100 mm/min. The maximum shear strength increased from 3.74 to

8.18 MPa at the forage stage and from 4.68 to 9.02 MPa at the seed stage. The minimum shear strength increased from 3.74 to 8.18 MPa, at the forage stage and 4.68 to 9.02 MPa at the seed stage as the knife bevel angle was increased from 30^0 to 70^0 at 10 mm/min rate of loading under quasi-static loading. The specific cutting energy increased from 34.1 to 101.1 MJ/mm^2 at the forage stage and from 36.5 to 142.7 MJ/mm^2 at the seed stage.

Chattopadhyay and Pandey (1999) conducted laboratory experiment to determine the impact cutting energy while cutting single stem of forage sorghum by the knife of a flail harvesting machine. The minimum cutting speed required for complete cutting was fairly insensitive to the knife rake angle. The minimum cutting speed increased from 12.9 to 18.0 m/s for a knife rake angle range of 20^0-60^0 as the knife bevel angle was increased from 30^0 to 70^0. Such low cutting speeds would not be capable of conveying the chopped forage successfully into the accompanying forage wagon. When the cutting speed was increased from 20-60 m/s, the cutting energy per unit cross-sectional area (specific cutting energy) for direct impact decreased by a factor of about three for the bevel angles.

Chattopadhyay and Pandey (2001) developed a mathematical model to estimate the impact cutting energy and power requirement using crop and machine parameters when harvesting forage crops by flail-type cutters. Values of the cutting energy and power requirements at different knife and operational parameters were found to be comparable with those obtained from laboratory investigations at the cutting speed range of 20-60 m/s in which the flail knives were operated for harvesting different types of thick-and thin-stemmed forage crops.

Neves *et al*. (2001) investigated on the blade materials commonly used in cane harvesting and concluded that the knife should be made from a material that was harder than what it was cutting. A gradual deformation of the blade was expected due to wear and prolonged use. Steel or a steel alloy was favoured due to its hardness and high tensile strength. Blades commonly used in sugar cane harvesters were made from SAE 5160 spring steel with 49HRC hardness.

Szymanek (2007) conducted an analysis of the cutting process of plant material. Results were presented in the aspects of an influence of the geometrical and kinematical parameters as well as the properties of plant material on the quality of cutting. Study concluded that in the cutting process the elementary value of resistance at plant material cutting depended on geometrical parameters (speed of dipping the knife into material, speed of sliding the edge) and on parameters which were characterized by the condition of the material (consistency). The elementary value of cutting resistance was given in determined limits.

Koloor and Ghaffar (2007) investigated on the effect of blade parameters on the cutting energy on soybean stems. An impact shear test apparatus was designed and constructed to measure the energy required for cutting soybean plant stems. The cutting velocities used in the experiments were 2.5, 3.75, 4.5 and5.45 m/s. The blade bevel angles were 18 ^{o}, 23 ^{o}, 28 ^{o}, 33 ^{o} and 38° and oblique angles were 10, 20, 30, 40 and 55°. The various tilt angles selected for the study were 15 ^{o}, 25 ^{o}, 35 ^{o}, 45 ^{o} and 55°.The resulted shows that the optimum value of specific cutting energy was obtained at blade bevel angle of 23^{o}, oblique angle of 30^{o} and tilt angle of 25^{o} and the blade velocity of 3.75 m/s.

CHAPTER - III

MATERIALS AND METHODS

In this chapter, the methodology adapted for the design of ergonomically improved cassava harvesting tool is explained. Agronomical and growth parameter of cassava crop is described. The various instrument used and methods adopted for taking observations in the field are described. The methodology adopted to determine the various physical and mechanical parameters cassava is described. The laboratory technique to measure soil resistance and force requirement is explained. The selection of different parameters which affect the manual cassava harvesting is explained. The design of improved harvesting tool is detailed. The procedure adopted for the design development of ergonomically improved harvesting tool is described. The selection of materials and its force analysis of a newly design tool using CAD software are described.

3.1 Crop and soil parameters

The physical properties of cassava crop and soil influence the performance of harvesting equipment. The important physical properties are crop stem diameter, root depth, bulk density, soil resistance, root spread area and force required to pullout the tuber. Manual harvesting method is commonly used for cassava cultivation. Hence, manual harvesting was taken for the investigation.

3.1.1 Girth diameter

Crop stem girth diameter is one of the important parameters that influences the design of stem holding unit in ergonomically improved cassava harvester. The minimum and maximum diameters of different cassava crop were taken. The stem girth diameter of thirty randomly selected cassava crop under the study were measured using vernier caliper with 0.05 mm least count. The observations were recorded and the average peduncle diameter was calculated.

3.1.2 Root depth

Crop root depth is one of the important parameters that influences force requirement of ergonomically improved cassava harvester. The minimum and maximum crop root depths of different cassava crop were taken. The crop root depth of randomly selected thirty cassava crop was measured using 30 cm steel rule.

3.1.3 Root spread

Crop root spread in horizontal plane is another important parameter that influences force requirement of ergonomically improved cassava harvester. The minimum and maximum crop root spread of different cassava crop was calculated. The crop root spread of randomly selected thirty cassava crops were measured along the major and minor axis in horizontal plane.

3.1.4 Bulk density

The bulk density of the soil was determined using the standard procedure. By using core cutter method, bulk density of soil can be quickly calculated and by determining the moisture content of the soil be calculated and hence the voids percentage. A high percentage of voids indicate poor compaction of soil. A cylindrical core cutter is a seamless steel tube. For determination of the density of the soil, the cutter is pressed into the soil mass so that it is filled with the soil without disturbing the core contents. The cutter filled with the soil is lifted up. The mass of the soil in the cutter is determined.

The density or unit weight (γ) is defined as the total weight of soil mass (w) per unit of its total volume (v). Here the weight and volume of soil comprise the whole soil mass. The voids in the soil may be filled with both water and air or only air consequently the soil may be wet, dry or saturated. Mathematically,

$$\text{Density, } \gamma = \frac{w}{v} \qquad \text{-----3.1}$$

The water content W, also called the moisture content is defined as the ratio of weight of water (w_W) to the weight of solids (w_s) in a given mass of soil. Mathematically,

$$\text{Water content, } w = \frac{W_w}{W_s} \times 100\% \qquad \text{------3.2}$$

Bulk density and soil moisture of the soil was calculated using the equation 3.1 and 3.2 respectively. The experiment was repeated for 5 times and observations were recorded. The average value of bulk density of selected samples was calculated.

3.1.5 Soil resistance

The soil resistance was determined using the standard procedure proposed by The American Society of Agricultural Engineers has established an Engineering Standard, ASAE S313.3 Feb99.

The soil cone penetrometer (Plate 3.1) is recommended as a measuring device to provide a standard uniform method of characterizing the penetration resistance of soils. The hand-operated soil cone penetrometer shown in figure has a cone and a graduated driving shaft. The force required to press the 30-degree circular cone through the soil, expressed in kilopascals, is an index of soil strength called the cone index.

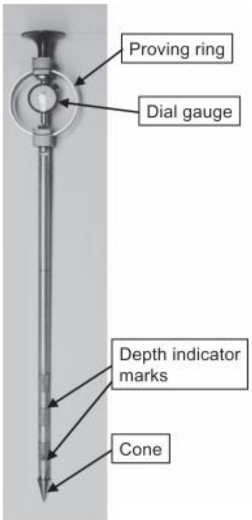


Plate 3.1 Soil cone penetrometer

The experiment was repeated for 5 times in different place in the field and observations were recorded. The average value of cone index was recorded and soil resistance was calculated.

3.1.6 Force required

The force required for uprooting plants of each cassava crop under flat planting and furrow planting was determined using a force measuring apparatus (Plate 3.2). The setup is composed of a metallic handle to which a modified spring balance is attached to show weight readings (in kilograms) during the cassava uprooting process. Modification of the spring balance was done by attaching a dummy dial beneath the original one. The idea is that the original dial comes back to zero at no load, thus there is the need to have a secondary (dummy) dial which will be dependent on the movement of the primary dial to assist in getting the right reading even after load is taken off the spring balance. However, the dummy dial was always reset to zero before each loading of the spring balance was done. The stem gripping mechanism is firmly attached to the cassava stem and with the help of the handle; a steady vertical force is applied to uproot the cassava. The reading as indicated by the dummy dial is then recorded after the uprooting process is ended.

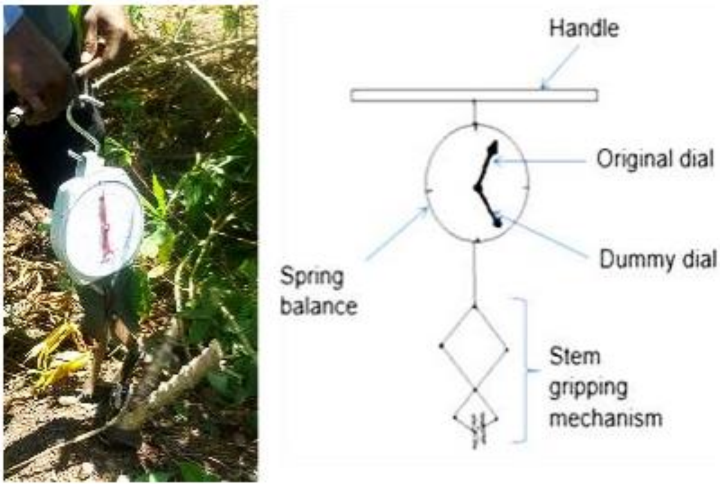


Plate 3.2 Force measuring apparatus

The force requirement for uprooting of 30 cassava crop was randomly measured from the field was measured.

3.2. Conceptual design

The length and width of the blades were designed based on evaluation of different cassava harvesting tools. The weight of the tool was designed and explained in this section. The handle length was designed based on the 95th percentile of hand breadth across thumb applicable to Indian agricultural workers as given in the anthropometric data book. The handle diameter was determined based on the 5th percentile of the palm width and hand grip diameter. The leverage force calculation was also done.

According to the above design considerations, three types of tools were fabricated and tested with different materials. The newly developed ergo refined cassava harvesting tools are shown in plate 3.5. Force requirement analysis of the newly developed tools were conducted as in 3d modelling software and compared with the conventional tools.

3.2.1. Handle length

Handle length is also affecting the comfort of the worker and the efficiency of the work. Good handle length gives a sufficient grip and sufficient leverage force to worker at the time of operation.

The length of the handle has to be designed based on the anthropometric data viz., palm width, Acromial height, Vertical grip reach and Hand length of the Indian male agricultural worker. The handle length of the collected five knives was measured using scale. The observations were recorded and the average handle length was calculated.

3.2.2. Handle diameter

Handle diameter of harvesting tool affects the comfort of the worker and the efficiency of the work. Observations of preliminary survey gave an idea about the shape of the handle. Mostly, cylindrical shape handles were used by the workers but the diameter of the handles varied from place to place. The diameter of the handle has to be designed based on the anthropometric data *viz*., grip diameter of the Indian male agricultural workers.

The handle diameter of the collected tools was measured using vernier calliper with 0.05 mm least count. The observations were recorded and the average handle diameter was calculated.

3.2.3. Weight of the tool

Weight is one of the main factors affecting efficiency of the operator in the harvesting operation. It has to be carried from one plant to another plant. It is also responsible for any musculoskeletal problems of the workers engaged in harvesting operations.

The weight of the collected tools was measured using an electronic balance, model: IWT 15/30, class III with least count of 40 g. The observations were recorded and the average weight of the tools was calculated.

3.2.4. Maximum force exerted by Operator

Maximum force exerted by Operator for harvesting is an important parameter. It will affect the comfort of the worker and the efficiency of the work. Observations of preliminary survey gave an idea about the force required for the cassava harvesting. The leverage force calculated based on type of lever and to be designed based on the strength parameter data *viz*., maximum pull force can exert by an Indian male agricultural worker. The observations were recorded and the average force requirement was calculated.

3.2.5. Human parameters

Human parameters *viz*., anthropometric data and strength parameter has to be considered in the design of cassava harvesting tool and the way in which it is used decides the performance of the tool. All pertinent anthropometric data and strength parameter were taken from "anthropometric and strength data of Indian agricultural workers for farm equipment design" (Gite*et al.*, 2009), published by CIAE, Bhopal. Important anthropometric data used for the design and their definitions are given in table 3.1.

Table 3.1. Anthropometric criteria used in cassava bunch harvesting tool design

S. No.	Anthropometric dimensions	Definition	Corresponding work space dimensions in cassava bunch harvesting tool	Purpose
i	Acromial height	The vertical distance from the standing surface to the top of the acromion. The subject stands erect & looks straight forward.	The vertical distance between the ground surface and the holding device.	Designing the height of the handle/lever of harvesting tool
ii	Vertical grip reach	The vertical distance from the standing surface to the height of the pointer held horizontal to the subject's fist when the arm is maximally extended upward. The subject stands erect &look straight forward	The vertical distance between the ground and handle to hold the lever in proper position	Designing the height of the handle/lever of harvesting tool
iii	Shoulder grip length	The horizontal distance from a pointer held in the subjects first to wall against which heists, measured with the arms extended forward& horizontal	The distance between the shoulder height to the handle grip at the time of harvest	Designing the height of the handle and deciding factor of the position the push/pull arrangement for grith holding mechanism
iv	Hand length	The distance from the base of the handle to the top of the middle finger measured along the long axis of the hand.	Handle designing	Designing the diameter of the handle of the tool designing.
v	Hand breadth across thumb	The breadth of the hand measured at the level of the distal end of the 1st metacarpal of the thumb.	Handle designing	Designing the length of the handle of the tool
vi	Grip diameter (inside)	The diameter of the widest level of a cone which the subject can grasp with his thumb and middle finger touching	Handle designing	Designing the diameter of the handle of the cutting knife and cassava stand hold.
vii	Pull strength at standing posture (N)	Pull strength with both hands in standing posture	Leverage force designing	To design the handle length and grip position in harvesting tool

3.2.6 Mechanical advantage

The musculoskeletal system includes bones, joints, skeletal muscles, tendons, and ligaments. Muscles generate force which tendons transfer it to bones; and the bones move if enough force is transmitted. The force must be enough to overcome the weight of the moving body part, gravity and other external resistance. Motion occurs at joints associated with either one or both ends of the bone. Biomechanics applies the principles of physics to human movement. Some joints work like levers, others like pulleys, and still others like a wheel-axle mechanism. Most motion uses the principle of levers. A lever consists of a rigid "bar" that pivots around a stationary fulcrum. In the human body, the fulcrum is the joint axis, bones are the levers, skeletal muscles usually create the motion and resistance can be the weight of a body part, the weight of an object one is acting upon, the tension of an antagonistic muscle and so forth.

In leverage force designing, the cutting action of the hand is considered similar to the first-class lever. The force exerted on crop holding unit, supporting frame is the pivoting point and the effort is the strain on handle. According to the anthropometric data available in the data bank, the maximum vertical grip reach is 2251 mm and minimum is 1703 mm with a mean value of 1991 mm. The maximum forearm hand length of a male worker is 530 and minimum is 375 mm and the mean value of the fore arm hand length is 455 mm. Cutting energy required to cut the banana bunch was determined in laboratory as explained in section 3.7.4. The maximum leverage force is determined using the above data and it applying to first class lever equation.

$$E_c \times L = W \times X \qquad \text{------------ (3.10)}$$

$$E_c = \frac{W \times X}{L} \qquad \text{------------ (3.11)}$$

Where,

E_c	=	Force required to cut the peduncle, J
L	=	Distance between shoulder joint to elbow joint, mm
X	=	Fore arm length, mm
W	=	Weight of the knife, kg

3.3. 3D modelling

SOLIDWORKS 2020 version was used for the force analysis of the cassava harvesting tool. Each component of the harvesting tool was developed individually in the modelling software and assembled. The dimensions and design are derived from the investigation done on cassava harvesting tools and based on the optimization of other parameters which was explained in previous sections. Three models were developed with different materials with same dimensions. The force analysis was done for these three harvesting tools on the same software and finalized the material for cassava harvesting tool.

The software now encompasses a number of programs that can be used for both 2D and 3D design. SOLIDWORKS is used to develop mechatronics system from beginning to end. At the initial stage, the software is used for planning, visual ideation, modelling, feasibility assessment, prototyping, and project management. The software is then used for design and building of mechanical, electrical, and software elements. Finally, the software can be used for management, including device management, analytics, data automation, and cloud services. The SOLIDWORKS 2020 software solutions are used by mechanical, electrical, and electronics engineers to from a connected design.

The SOLIDWORKS interface is dynamic in that different toolbars and menus appear depending on the active document type. The entire machine was designed using SOLIDWORKS. Every single element in the model was modelled individually and finally combined it using the software.

3.4. Conceptual design development

The different unit operations for cassava harvesting are loosening the roots and pulling up the plants, removing soil and separating the roots, collecting the roots and loading the roots for transport. The traditional practice of cassava harvesting includes loosening the soil using crowbar, if the soil is compact. The plant is pulled up gently without dragging the roots. The dragging can cause bruises and cuts to roots which may lead to early deterioration. The cassava harvesting is a tedious work and requires around 40-man days/ha.

Musculoskeletal problems including back pain, shoulder pain, wrist pain and some minor injuries were reported during the field survey. The whole weight of the bunch and plant was supported by the worker during pulling and hence back pain was reported by some workers. A sudden impact force was generated on the hand and back bones when the harvesting. Due to the sudden shock, shoulder pain, neck pain and joint dislocation were reported. Injuries from the traditional harvesting tools were reported.

A cassava harvesting tool was conceptualized to hold the stem of cassava conveniently and pull the entire plant from the below ground. The unit was designed to eliminate the hazards in handling cassava bunches during and after harvest. With this unit, the manual pulling of cassava could be eliminated.

3.4.1. Main handle

The main pole was designed by three different materials like round pipe, square pipe and wood. Design for high strength having dimensions based on anthropometric data and strength parameters. The grip diameter, standing height of a worker and mechanical advantage was considered for the design of main handle. This part was designed in the SOLIDWORKS software and force analysis was done by simulation software.

3.4.2. Supporting Legs

One supporting leg were attached with the main pole and it is pivoted to main handle with in both sides. Supporting legs and main pole together act like a I^{st} class lever system to get sufficient mechanical advantage and balance a during harvesting.

3.4.3. Holding Unit

A holding unit was designed for clamping the stem at the time of harvest. A spring-loaded cam arrangement was provided in the holding unit. The cam was made of wood with base circle of radius and limit circle based on the maximum and minimum diameter of the girth of cassava. The cam profile design is shown in Fig 3.1. Cam lock was held under tension with the help of 1.6 mm wire spring. The spring keeps the cam always in closed position. It could be opened by pulling clutch wire for holding the cassava crop. A wooden handle was provided at the end of the clutch wire for easy operation as shown in plate 4.1. The functioning of cam is shown in plate 4.2.

3.5. Working

The cassava stand was designed in such a way that it can be dismantled and assembled easily. The weight of the unit was reduced to carry easily within the cassava field by a single person. The height of the unit was 2020 mm and width were 880 mm.

During operation, the worker lifts the stand up to the height of the peduncle bunch and pulls the clutch wire to open the cam and clamp the peduncle into the holding. Now the stand will be in hanging position in the air and it would slowly come down to the ground when cutter cuts down the plant at the middle. Cutter can separate the bunch from the plant by cutting the bunch at the peduncle. Due to the gravity the bunch would move down along with the stand rotating the cam in clock wise direction by frictional force between cam and peduncle. The peduncle would get locked and holds the bunch due to the rotation of the cam. Cassava stands with the bunch lands on the ground and rest with the three-leg holding the bunch at the shoulder height of a normal man. After that, it is easy for the worker to carry the bunch on his shoulder from the stand directly by releasing from holding unit with the help of clutch wire.

CHAPTER- IV

RESULTS AND DISCUSSION

In this chapter, the various physical and mechanical parameters of cassava crop which affects the harvesting operation of cassava are analyzed. The features of conventional cassava harvesting tool are analyzed from growing parts of Tamil Nadu and Kerala. The sequence of development of cassava harvesting tool and its effect in reducing the musculoskeletal injuries and human energy expenditure in handling the operation are explained. The anthropometric fit of cassava harvesting tool is reported and the ergonomic benefits of newly tool are explained. The force analysis of tool is done by CAD software and reported.

4.1 Crop and soil parameters

The physical properties of cassava crop and soil influence the performance of harvesting equipment. The important physical properties are crop stem diameter, root depth, bulk density, soil resistance, root spread area and force required to pullout the tuber was analyzed and reported. Manual harvesting method is commonly used for cassava cultivation. Hence, manual harvesting was taken for the investigation.

4.1.1 Girth diameter

The stem girth diameter of randomly selected cassava crop was measured as explained in section 3.1.1. The results were statistically analyzed. It was observed that the minimum and maximum stem girth diameter of cassava crop during harvesting time was 20.80 and 50.67mm respectively.

4.1.2 Root depth

Crop root depth is one of the important parameters that influences force requirement of ergonomically improved cassava harvester. The minimum and maximum crop root depth of different cassava crop were taken and recorded as explained in section 3.1.2. The results of 30 roots were statistically analyzed. It was observed that the minimum and maximum root depth of cassava crop during harvesting time was 179.67 and 276.87 mm respectively.

4.1.3 Root spread

Crop root spread area is an important parameter that influences force requirement of cassava harvester. The minimum and maximum crop root spread area of different cassava crop was calculated and recorded as explained in section 3.1.3. The results of 30 root were statistically analyzed. It was observed that the average root spread of cassava crop during harvesting along the major and minor axis in horizontal plane was 156 and 300 mm respectively.

4.1.4 Bulk density

Bulk density and soil moisture of the soil was calculated as explained in section 3.1.4. The experiment was repeated for 5 times and observations were recorded. The average value of bulk density of selected samples was 1.53 g/cm^3 and the moisture content was 16.36 %. But the moisture content may vary depending of harvesting practices.

4.1.5 Soil resistance

The soil resistance was determined using the standard procedure as explained in section 3.1.5. and the observations were recorded. The average soil resistance of soil from the depth 10 cm to 40 cm was varied from 1.13 to 4.08 MPa.

4.1.6 Force required

The force required for uprooting plants of each cassava crop under flat planting and furrow planting was determined as explained in the section 3.1.6. The force requirement for uprooting of 30 cassava root was randomly measured from the field and recorded. The average value was 150 kgf. The force required is varying based on the crop root depth, soil moisture content and root spread area.

4.2. Conceptual design consideration of the cassava harvesting tool

The length and width of the blades were designed based on evaluation of different cassava harvesting tools. The weight of the tool was designed and explained in 3.2 section. The handle length was designed based on the 95th percentile of hand breadth across thumb applicable to Indian agricultural workers as given in the anthropometric data book. The handle diameter was determined based on the 5th percentile of the palm width and hand grip diameter.

All pertinent anthropometric data required for the design of handle for harvesting tool was taken from “anthropometric and strength data of Indian agricultural workers for farm equipment design” (Gite *et al.,* 2009), published by CIAE, Bhopal were given in Table 4.1.

Table 4.1 Human parameters required for the conceptual design of harvesting tool

S. No.	Parameter	Percentile values		Range of values		Mean
		5th	95th	Maximum	Minimum	
1	Acromial height, mm	1270	1474	1625	1035	1372
2	Vertical grip reach, mm	1856	2126	2251	1703	1991
3	Shoulder grip length, mm	612	863	882	520	738
4	Hand length, mm	164	197	214	148	181
5	Hand breadth across thumb, mm	86	111	135	74	72
6	Grip diameter (inside), mm	43	56	62	37	49
7	Middle finger palm grip diameter, mm	24	32	36	21	28
8	Forearm hand length, mm	416	495	530	375	455

The height of the handle was designed based on Acromial height and Vertical grip reach. The 5th percentile of the acromial height was considered to fix the height of handle. The height of the handle must be less than 5th percentile value of the vertical grip reaches i.e., it should be less than 1856 mm. The diameter of the handle of harvesting tool was designed based on the 5th percentile value of the Hand length, Grip diameter (inside) and Middle finger palm grip diameter. The 5th percentile value of forearm hand length and shoulder grip length or 95th percentiles of hand breadth across thumb were considered for the leverage force calculation.

4.2.1 Handle length

The length of the handle has to be designed based on the anthropometric data viz., palm width, Acromial height, Vertical grip reach and Hand length of the Indian male agricultural workers. The handle length of tool was calculated minimum as 1474 mm.

4.2.2 Handle diameter

The diameter of the handle has to be designed based on the anthropometric data *viz*., grip diameter of the Indian male agricultural workers. The handle diameter of the collected tools was measured as explained in section 3.2.2. The average handle diameter was calculated recorded. It was decided that the diameter should be less than 72 mm peripheral length.

4.2.3 Weight of the tool

The weight of different tools was measured using an electronic balance, model: IWT 15/30, class III with least count of 40 g. The observations were recorded and the average weight of the tools was calculated as 2.53 kg.

4.2.4 Maximum force exerted by Operator

Maximum force exerted by Operator for harvesting is an important parameter. It will affect the comfort of the worker and the efficiency of the work. Observations of preliminary survey gave an idea about the force required for the cassava harvesting. The leverage force calculated based on type of lever and to be designed based on the strength parameter data *viz.*, maximum pull force can exert by an Indian male agricultural worker. The observations were recorded and the average force requirement was calculated.

4.2.5. Mechanical advantage of lever

The leverage weight of the harvesting tool was designed according to the leverage force consideration, as described in section 3.2.6. The force required to pull the cassava was calculated in field as explained in section 3.1.6. The distance between shoulder joint to elbow joint and fore arm length was calculated from anthropometric data given in table 4.1. Leverage force was calculated using online software "Engineers edge solutions" as 1691.23 J/m^2. The cutting energy for harvesting cassava was 907.11 J/m^2, which is less than the maximum leverage force of 1691.23 J/m^2.

4.3. Force analysis using 3D modelling software

SOLIDWORKS 2020 version was used for the force analysis of the cassava harvesting tool. Each component of the harvesting tool was developed individually in the modelling software and assembled. The dimensions and design are derived from the investigation done on cassava harvesting tools and based on the optimization of other parameters which was explained in previous sections. Three models were developed with different materials with same dimensions. The force analysis was done for these three harvesting tools on the same software and finalized the material for cassava harvesting tool.

The volumetric property of the static pipe and static rod are mentioned in below tables in that the mass, volume, density and weight of the pipe is found that 4.50 kg, 0.00057087 m^3, 7,900 kg/m^3 and 44.1968 N respectively for rod are 13.5019 kg, 0.0017091 m^3, 7,900 kg/m^3 and 132.318 N respectively.

The important material properties of static pipe such as are yield strength, tensile strength and mass density are 351.57 N/mm^2, 420.5 N/mm^2 and 7,900 kg/m^3 respectively, these mentioned standard volumetric and material properties are generally use for develop manually cassava harvesting tool. Static rod is stronger than static pipe. The mass and density of a static rod is greater than of a static pipe. The thermal efficiency of the static pipe and static rod is the same.

As yield strength is related to deformation which is a result of applied stress, so here the yield strength of rod is more than the pipe. Hence the rod is able to resist the stress which result in increase in factor of safety. Tensile strength of rod and pipe are almost same that indicates both of the component are resilient to the tensile force. Permanent deformation take place if the stress exceeds 200 kN/mm^2 for pipe. Shear modulus of the pipe is $77kN/mm^2$ and rod is $77kN/mm^2$.

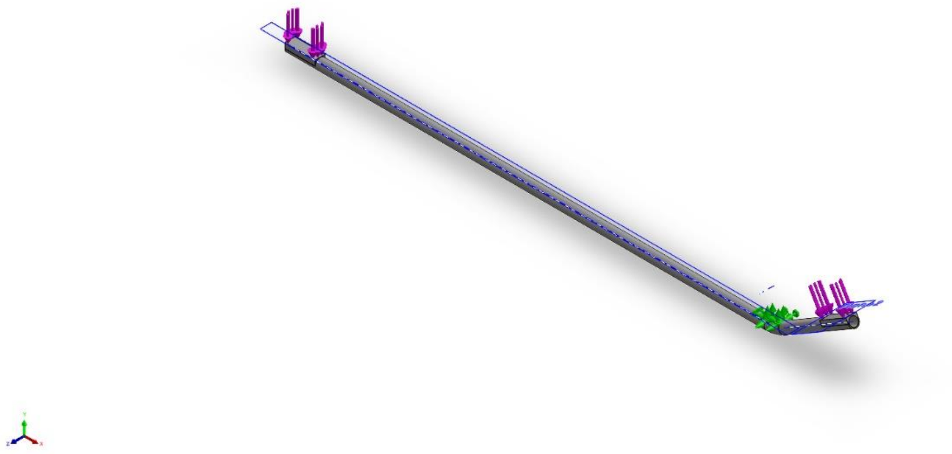


Plate 4.1 Static pipe

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude2 	Solid Body	Mass:4.50987 kg Volume:0.00057087 m^3 Density:7,900 kg/m^3 Weight:44.1968 N	

Study name	Static pipe
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFE Plus
Inplane Effect:	Off

Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS

Units

Unit system:	SI (MKS)
Length/Displacement	Mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Materials Properties of static pipe

Model Reference	Properties	Components
	Name: **AISI 1020** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **3.51571e+08 N/m^2** Tensile strength: **4.20507e+08 N/m^2** Elastic modulus: **2e+11 N/m^2** Poisson's ratio: **0.29** Mass density: **7,900 kg/m^3** Shear modulus: **7.7e+10 N/m^2** Thermal expansion coefficient: **1.5e-05 /Kelvin**	**Solid Body**

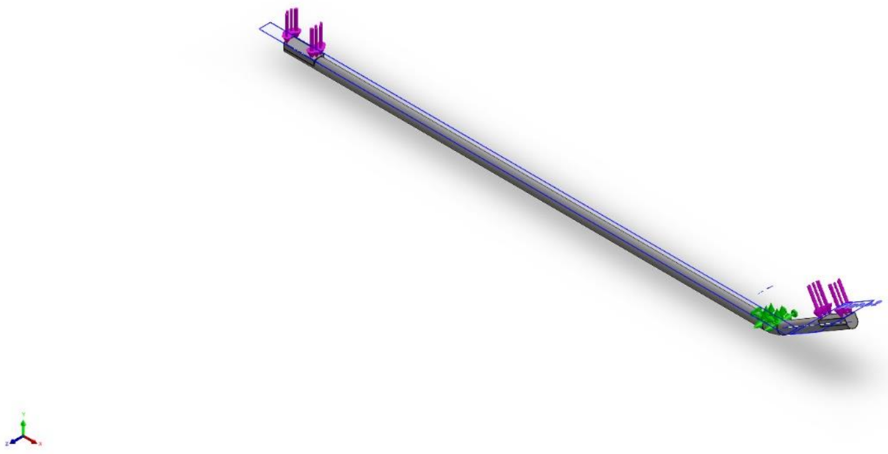
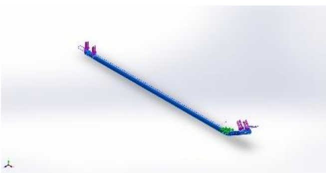


Plate 4.2 Static Rod

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude2 	Solid Body	Mass:13.5019 kg Volume:0.0017091 m^3 Density:7,900 kg/m^3 Weight:132.318 N	

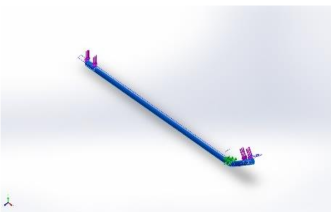
Study name	Static Rod
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFE Plus

Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS

Units

Unit system:	SI (MKS)
Length/Displacement	Mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Materials Properties of static rod

Model Reference	Properties	Components
	Name: **AISI 1020** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **3.51571e+08 N/m^2** Tensile strength: **4.20507e+08 N/m^2** Elastic modulus: **2e+11 N/m^2** Poisson's ratio: **0.29**	**Solid Body**

	Mass density:	**7,900 kg/m³**	
	Shear modulus:	**7.7e+10 N/m²**	
	Thermal expansion coefficient:	**1.5e-05 /Kelvin**	

Design analysis performed using **SOLIDWORKS 2020**

4.4. Conceptual design development

The different unit operations for cassava harvesting are loosening the roots and pulling up the plants, removing soil and separating the roots, collecting the roots and loading the roots for transport. The traditional practice of cassava harvesting includes loosening the soil using crowbar, if the soil is compact. The plant is pulled up gently without dragging the roots. The dragging can cause bruises and cuts to roots which may lead to early deterioration. The cassava harvesting is a tedious work and requires around 40-man days/ha.

Musculoskeletal problems including back pain, shoulder pain, wrist pain and some minor injuries were reported during the field survey. The whole weight of the bunch and plant was supported by the worker during pulling and hence back pain was reported by some workers. A sudden impact force was generated on the hand and back bones when the harvesting. Due to the sudden shock, shoulder pain, neck pain and joint dislocation were reported. Injuries from the traditional harvesting tools were reported.

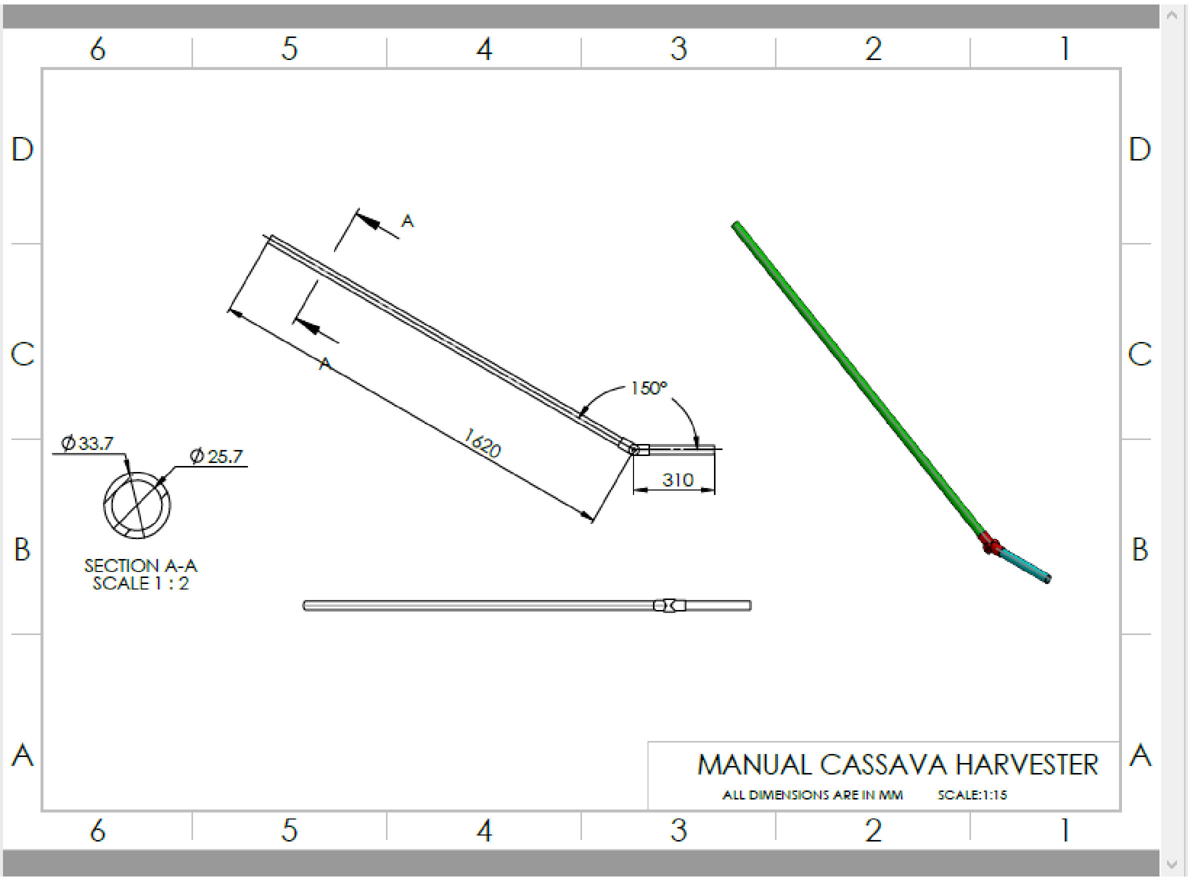


Figure 4.1. Conceptual design of manual cassava harvesting tool in SOLIDWORKS 2020 software

A cassava harvesting tool was conceptualized to hold the stem of cassava conveniently and pull the entire plant from the below ground. The unit was designed to eliminate the hazards in handling cassava bunches during and after harvest. With this unit, the manual pulling of cassava could be eliminated.

4.4.1. Main handle

The main pole was designed by three different materials like round pipe, square pipe and wood. Design for high strength having dimensions based on anthropometric data and strength parameters. The grip diameter, standing height of a worker and mechanical advantage was considered for the design of main handle. The length of the handle is decided from the analysis is 1600 mm and the handle diameter is 20 mm and the material are M.S. round pipe.

4.4.2. Supporting Legs

One supporting leg were attached with the main pole and it is pivoted to main handle with in both sides. Supporting legs and main pole together act like a Ist class lever system to get sufficient mechanical advantage and balance a during harvesting. The material selected was MS pipe and the length of supporting leg was 250 mm.

4.4.3. Holding Unit

A holding unit was designed for clamping the stem at the time of harvest. A spring-loaded cam arrangement was provided in the holding unit. The cam was made of wood with base circle of radius and limit circle based on the maximum and minimum diameter of the girth of cassava. The cam profile design is shown in figure.4.3. Cam lock was held under tension with the help of 1.6 mm wire spring. The spring keeps the cam always in closed position. It could be opened by pulling clutch wire for holding the cassava crop. A wooden handle was provided at the end of the clutch wire for easy operation. Cam lock arrangement shown in the figure. 4.4.

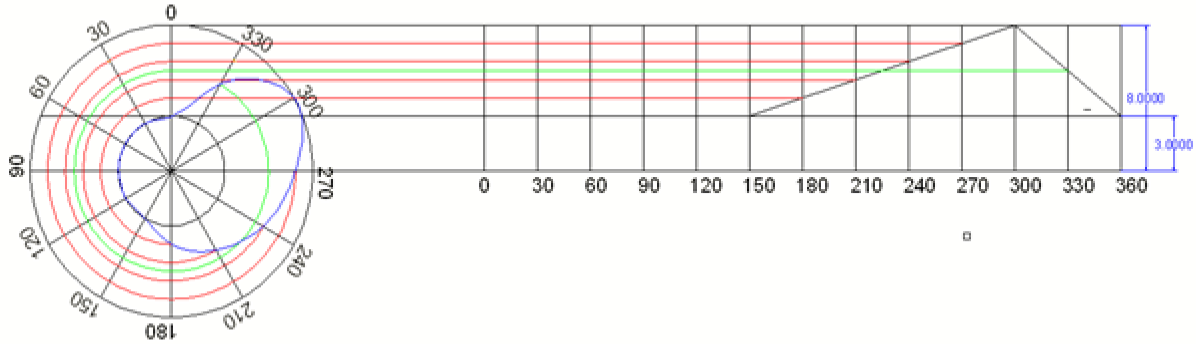


Figure.4.2. Cam profile design of cassava holding unit

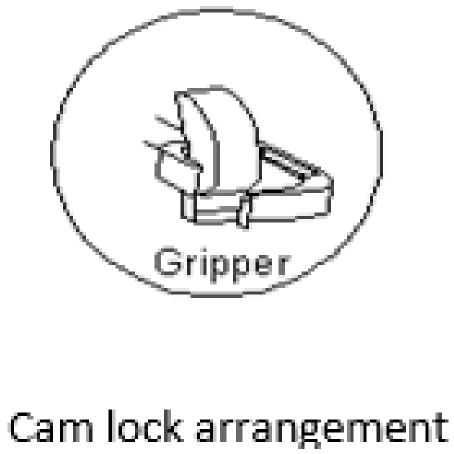


Figure.4.3. Cam lock arrangement of holding unit

Table 4.2 Detailed specification of the harvesting tool

Part of Cassava stand	Parameters	Specifications
1. Handle	Total height of the pole, mm	1600
	Pipe diameter, mm	20
	Pipe thickness, mm	2
	Material	Mild steel pipe
2. Holding unit	Length, mm	140
	Width, mm	80
	Thickness, mm	30
	Flat thickness, mm	5
	Material	Mild steel pipe
3. Cam	Base circle radius, mm	30
	Limit circle radius, mm	80
	Width of the cam, mm	25
	Material	Wood
4. Supporting leg	1. Pipe diameter, mm	20
	2. Pipe thickness, mm	2
	3. Horizontal length, mm	200
	4. material	MS pipe

4.5. Working

The harvesting tool was designed in such a way that it can be dismantled and assembled easily. The weight of the unit was reduced to carry easily within the cassava field by a single person. The handle height of the unit was 1600 mm and width weight were 2.53 kg.

During operation, the worker lifts the tool to the ground level and pulls the clutch wire to open the cam and clamp the stem into the holding. Now the tool will be in locking position and it would slowly pull the handle to back. The stem would get locked and holds the stem due to the rotation of the cam. The rotating action of tool at pivoting point would help to pull out the cassava from the soil with minimum effort (Fig 4.4). The maximum pull force required to pull cassava was 150 kg and 23 kgf was the maximum force could be excreted by a man at standing posture. So, the mechanical advantage of the lever will help to reduce the force requirement to pull the cassava from the ground. As per the design 16 kgf was required to pull the cassava using this manual tool and it is easy for the worker to pull and carry the cassava from the field.

CHAPTER - V

SUMMARY AND CONCLUSION

Harvesting of tuber/rhizome is an important operation in root crop cultivation which requires immediate attention for developing appropriate mechanical harvesting technology. Conventional method harvesting tubers/rhizomes is labour intensive; require skilled labour to dig out from soil. The features of conventional cassava harvesting tool are analysed from cassava growing parts of Tamil Nadu and Kerala. Tough, planting cassava in a slanted positions offers the best in terms of uprooting force requirement and rooting depth regardless of cassava variety. Different methods of cassava harvesting are used in different places. Average weight of cassava tuber bunch will be (5-20 kg) and in the case of hybrid variety it will go more than (25-35 kg). So, the conventional type harvesting mentioned above causes drudgeries and workers face many types of musculoskeletal problems. Hence research was carried out to design analysis of a manual cassava harvesting tool.

As per the conceptual working of tool, is to pulls the wire to open the cam and clamp the steam into the holding. Now the tool will be in locking position and it would slowly pull the handle to back. The stem would get locked and holds the stem due to the rotation of the cam. The rotating action of tool at pivoting point would help to pull out the cassava from the soil with minimum effort. So, the maximum pull force required to pull cassava was 150 kg and 23 kgf was the maximum force could be excited by a man at standing posture. So, the mechanical advantage of the lever will help to reduce the force requirement to pull the cassava from the ground. As per the design 16 kgf was required to pull the cassava using this manual tool. It is suggested that the manual uprooting technique is best suited for soils with relatively higher moisture content and best efficiency of manual harvesting is achieved when the upper cassava plant biomass is removed before harvesting.

5.1 The following consideration were made for conceptual design

- The minimum and maximum stem girth diameter of cassava crop during harvesting time was 20.80 mm and 50.67 mm respectively.
- The minimum and maximum root depth of cassava crop during harvesting time was 179.67 mm and 276.87 mm respectively.
- The average root spread of cassava crop during harvesting along the major and minor axis in horizontal plane was 156 mm and 300 mm respectively.
- The average value of bulk density of soil samples collected was 1.53 g/cm^3 and the moisture content were 16.36%.

- The average soil resistance of soil from the depth 10 cm to 40 cm was varied from 1.13 to 4.08 MPa.

5.2 Ergonomic consideration for conceptual design

- The force required for uprooting of cassava root was obtained to be 150 kgf.
- The conceptual design was carried out for 5^{th} and 95^{th} percentile based on the evaluation of different cassava harvesting tools.
- The length of the handle is decided from the analysis is 1600 mm and the handle diameter is 20 mm and the material are M.S. round pipe.
- The length of supporting leg was 250 mm and the material selected was M.S. pipe.
- Cam lock was held under tension with the help of 1.6 mm wire spring. The spring keeps the cam always in closed positions.
- Tool was designed for carry easily within the field by a single person.

5.3 Force analysis were conducted for different components and following material recommendation was analysed

- The important material properties of static pipe such as are yield strength, tensile strength and mass density are 315.57 N/mm^2, 420.5 N/mm^2 and 7,900 kg/m^3 respectively.
- Static rod is stronger than static pipe.
- The wooden material not suitable for this tool.
- The mass and density of a static rod is 13.5 kg and 7,900 kg/m^3.

ABSTRACT

Mechanisation for cassava harvesting is still very low in most cassava growing areas of India due to topographic constraints society of labours. The man-machine system of cassava harvesting is still a major challenge to many small-scale farmers who rely on indigenous tools and implements. Cassava is the most widely cultivated root crop and in southern states of India (Kerala and Tamil Nadu) and is grown across a broad range of agro-climatic conditions. Cassava can be cultivated under both irrigated and rainfed conditions. Under irrigated conditions, this crop can be cultivated throughout the year whereas under rainfed conditions; May-June is the best time before monsoon season starts. Our farmers are not able to buy a tractor or large harvesting machine, hence manual harvesting tools help them for harvesting. Manual cassava harvesting is difficult and full of drudgery especially during the dry seasons when the soil moisture content is low; mechanized alternatives are way beyond the reach of poor farmers. These includes manual devices such as cutlasses and hoes and semi mechanized devices such as prairie mouldboard ploughs. Ridges are used to split the ridge along the crest and pulling by using specially designed blades to cut below the tubers. Generally, animal and tractor drown single disc ploughs are used to harvest cassava. The major components of the harvester include a support stand, lifting arm, lifting medium and the clamp. Best efficiency of manual harvesting tool is achieved when cassava plants are coppiced before harvesting. Some of the design considerations include ease of reproducibility and ability to lift the cassava with minimal damage. The most difficult and cost intensive field operation in cassava performance may be poor, if ergonomics are not given attention. The improper posture during the work and heavy demand on workers biological system, equipment operation cause clinical or anatomical disorders and will affects the health. Design analysis were conducted based on girth diameter of cassava stem in the range of 20.80 to 50.67 mm, at depth ranging from 179.67 to 276.87 mm. The soil resistance was recorded as 1.13 to 4.08 Mpa. The average force required for uprooting was about 150 kgf. Also observed that rod section was superior over pipe section of the handle of the harvesting tool.

REFERENCES

Adetan, D. A., Adekoya, L. O., & Aluko, O. B. (2003). Characterisation of some properties of cassava root tubers. *J. Food. Eng.* 59(4):349–353.

Agbetoye, L. A. S., Ademosun, O. C., Ogunlowo, A. S., Olukunle, O. J., Fapetu, O. P., & Adesina, A. (2003). Engineering challenges in developing indigenous machinery for cassava production and processing. *Proc. Ann. Conf. of the Nigerian Soc. Eng.* (Lagelu2003):80–86.

Agrawal, K. N., R. K. P. Singh and K. K. Satapathy. 2010. Anthropometric considerations of farm tools/machinery design for tribal workers of north east India. *Agric. Eng. Int. CIGR J.* 12(1):143-149.

Akcali, I. D., Ince, A., &Guzel, E. (2006). Selected physical properties of peanuts. *Int. J. Food. Prop.* 9(1):25–37.

Akrithi, C. B. 1974. Mechanical Characteristics of Maize Stalks in Relation to the Characteristics of Cutting Blade. *J. Agric. Eng. Res.* 19: 1-12.

Amponsah, S. K., Addo, A., & Gangadharan, B. (2018). Review of Various Harvesting Options for Cassava. https://doi.org/10.5772/intechopen.71350

Anonymous, 2000. Banana Harvesting. *http://www.doleeurope.com*.

Anonymous, 2000. The ergonomic evaluation of hand tool and its accidents of Indian agricultural workers. *Coordinating cell AICRP on Ergonomics and Safety in Agriculture,* CIAE Bhopal.

Anonymous, 2001. All India Coordinated Research Project in Home Science: *Annual Report,* ICAR, New Delhi, India.

Anonymous, 2006. Papyrus Australia Ltd, *http://www.papyrusaustralia.com.au/*.

Anonymous, 2009. Technical report on physiological response of agricultural workers in various operations by Central Institute of Agricultural Engineering (CIAE), Bhopal, India.

Anonymous, 2010. *National Horticulture Board,* http://*www.indiastat.com*

Aware and Powar. 2008. Mathematical modelling of anthropometric data of agricultural workers. *Int. J. Agric. Eng.* 1 (2):52-64.

Bobo bee, E., Okyere, J., Twum, A., Congress, R. N. (CIGR. X. W., & 1994, undefined. (1994). Performance evaluation of a mechanical cassava harvester.

Chalachai, S., Soni, P., Chamsing, A., & Salokhe, V. M. (2013). Acritical review of mechanization in cassava harvesting in Thailand. *Int. Agric. Engg. J.*22(4),81–93.

Chancellor, W.J. 1958. Energy requirements for cutting forage. *J. Agric. Eng.* 39 (10):633-64.

Chattopadhyay, P. S and K. P. Pandey. 2001. Cutting behaviour of sorghum stalk using a flail-cutter: a mathematical model and its experimental verification. *J. Agric. Eng. Res.*78(4):337-39.

Chattopadhyay, P. S and K. P. Pandey.1999. Effect of Knife and Operational Parameters on Energy Requirement in Flail Forage Harvesting. *J. Agric. Eng. Res*73: 3-12.

Das, F.C. and C.P. Gupta. 1972. Cutting resistance of sugar cane stem. Presented at the 10th Annual meeting of ISAE.

FAOSTAT. (2018). Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/QC(Accessedon10/04/2020).

Ganguly, S. and S. R Datta. 1975. Prediction of cost from peak heart rate in lower extremity amputees. *Bio-mech. Eng:* 10:52-55.

Geoff, B. and R. Shlomowitz. 1992. The Lag in the Mechanization of the Sugarcane Harvest: Some Comparative Perspectives. *Agricultural History*, 66 (3):61.

Grandjean. 1973. Ergonomics in home, TAYLOR and FRANCIS, Ltd., London. Saha, P.N. 1976. The practical use of some physiological research methods for assessment of work stress. *J. Ind. Asso. Physio*: 4 (1):9- 13.

Hillocks, R. J. (2009). Cassava in Africa. Cassava: Biology, Production and Utilization, 41–54.https://doi.org/10.1079/9780851995243.0041.

Intaranont, K. and S. Srithongchai. 1993. Study of work strain of sugar-cane cutters. *Agric. Eng. J.* 2(1&2):49-57.

Jelani, A. R., D. Ahmad, A. Hitam, A. Yahya, and J. Jamak.1999. Reaction force and energy requirement for cutting oil palm fronds by spring powered sickle cutter. *J. Oil Palm. Res.* 11(2): 114-122.

Kanchan, T., K. Krishan, A. Sharma, G. Ritesh and Menezes. 2010. A study of correlation of hand and foot dimensions for personal identification in mass disasters. *Forensic Sci. Int.* 199:112. e1–112.

Kolawole, O. P., Agbetoye, L. A. S., & Ogunlowo, A. S. (2007). Strength and elastic properties of cassava tuber. *Int. J. of Food Engg.*3(5).https://doi.org/10.2202/1556-3758.1225.

Kolawole, O.P., Ayodeji. L., Agbetoye. S., &Ogunlowo, A. S. (2011). Evaluation of cassava mash dewatering methods. 3(February), 23–30.https://doi.org/10.2202/1556-3758.1088.

Lom changkum. C., Junsiri, C., Sudajan. S., & Laloon, K. (2020). A study on the mechanical characteristics of cassava tuber cutter. *Int. J. of Agric. Technol.* 16(1),63–76.

Koloor, R. T., and G. Kiani. 2007. Soybean stems cutting energy and the effects of blade parameters on it. *Pakistan Journal of Biological Sciences*, 10 (9): 1532-1535.

Kumar, A., J. K. Singh, D. Mohan and M. Varghese. 2006. Ergonomic evaluation of hand tools. injuries among Indian farmers. *J. Agric. Eng.* 43(4): October-December.

McRandal, D. M. and McNulty .1978. Impact cutting behaviour of forage crops II. Field tests. *J. Agric. Eng.* 23(3) :329-338.

McRandal, D. M. and P. B. McNulty. 1978. Impact cutting behaviour of forage crops I. Mathematical models and laboratory tests *J. Agric. Eng. Res.* 23(3):313-328.

Mohankumar. 2009. Ergonomical evaluation and refinement of coconut and areca nut tree climbing devices. Unpublished M.E. (Ag.) Thesis, Department of Farm Machinery, Tamil Nadu Agricultural University, Coimbatore, India.

Mohsenin, N. N. (1986). Physical properties of plant and animal materials. *Nat. Res.* 8(3):567-678.

Nag, P. K., and A. Nag. 2004. Review Article on Drudgery, Accidents and Injuries in Indian Agriculture. National Institute of Occupational health, *Indian Council of Medical Research India Industrial Health,* 42: 149–162.

Nag, P.K. 1981. Predicting maximum oxygen uptake of workers engaged in agricultural tasks. *J. Hum. Ergo.*28(3),158-64.

Nag, P.K., A. Goswami, S. P. Ashtekiar and C. K. Pradhan. 1988. Ergonomics in sickle operation. *App. Ergo.* 19: 233-239.

Neves, J. L. M., A. S. Marchi, A. A. S. Pizzinato, and L. R. Menegasso. 2001. Comparative testing of a floating and a conventional fixed base cutter. *Proceedings of the International Society of Sugar Cane Technologists*, 24: 257-262.

O'Dogherty, M. J and G. E. Gale. 1986. Laboratory studies of the cutting of grass stems. *J. Agric. Eng. Res.*35(2): 115-129.

O'Dogherty, M. J and G. E. Gale. 1991. Laboratory studies of the dynamic behaviour of grass, straw and polystyrene tube during high-speed cutting. *J. Agric. Eng. Res*, 49: 33-57.

Ospina, B., Cadavid, L. F., García, M., & Alcalde, C. (2002). Mechanization of cassava production in Colombia. Cassava Research and Development in Asia,277–287.

Oupathum, C., Charee, S., Sudajan, S., & Thivavarnvongs, T. (2019). Effects of Moisture Content and Knife Bevel Angle on Shearing Properties of Cassava Stems. IOP Conference Series: Earth and Environmental Science,301(1).https://doi.org/10.1088/1755-1315/301/1/012010.

Pheasant and O’Neill. 1975. Performance in gripping and turning: a study in hand/handle effectiveness. *Applied Ergonomics*, 6:205-208.

Prasad, J., and C. P. Gupta.1975. Mechanical Properties of Maize Stalk as Related to Harvesting. *J. Agric. Eng. Res*, 20; 79-87.

Saha, P.N. 1976. The practical use of some physiological research methods for assessment of work stress. *J.Ind. Asso. Physio.* 4 (1):9- 13.

Sawkar, S. P. 1999. Ergonomic evaluation on occupational workload, posture musculoskeletal problems of the female agricultural labourers in Dharwad, Karnataka, state Unpublished Ph.D. thesis, SNDT, women’s university, Mumbai.

Sen, R. N. 1969. Tentative classification of strains in different types of jobs according to the physiological responses of young Indian workers in comfortable climates. *ICMR report, Indian Council of Medical Research*, New Delhi.

Shadrack, K. A., Joseph, N. B., Joseph, M.-A., Eric, O. D., Jonas. A., Adelaide, A., & Enoch, B. (2017). Performance of an improved manual cassava harvesting tool as influenced by planting position and cassava variety. *African J. of Agric. Res.* 12(5),309–319.https://doi.org/10.5897/AJAR2016.11874.

Simonyan, K. (2015). Some engineering properties of Cassava tuber related to it speeling mechanization. *Umudike J. of Engg. Tech.* (*UJET)*, 1(1), 12–24.

Singh, M. S. and K. N. Singh. 1978. Force Requirements of Different Sickles *J. Agric. Eng. Res*. 15(1): 11-18.

Susheela, P. Sawkar, M.A. Varghese, P.N. Saha and K.V. Ashalatha. 2001. Ergonomic assessment of occupational workload and rest allowances for female agricultural labourers in Dharwad, Karnataka. *Humanizing work and work environment*, 140-144.

Szymanek, M. 2007. Analysis of cutting process of plant material. TEKA Kom. Mot. Energ. Roln. – OL PAN. 7A, 107–113.

Thambidurai, R. 2007. Ergonomic evaluation of weeders. Unpublished Ph.D. (Ag.) Thesis, Department of Farm Machinery, Tamil Nadu Agricultural University, Coimbatore, India.

Thangdee, D. (2012). Development of Cassava Digger and Conveyor Units. *Americ. J. Exper. Agric.*2(3),458–469.

Thiyagarajan, 2006; Ergonomical evaluation of sugarcane harvesting knives, sugarcane detrasher and finger type rotary weeder for paddy Unpublished M.E. (Ag.) Thesis, Department Agricultural University of Farm Machinery, Tamil Nadu, Coimbatore, India.

Tiwari, V.K. and G.S. Philip. 2002. Occupational stress on Indian female agricultural workers. Paper presented at 37th annual convention of ISAE held at Udaipur.

USDA, N. (2003). Plant guide–cassava: Mani hotesculenta Crantz. Baton Rouge, Louisiana and Pacific Islands. Mongmong, Guam.

Visvanathan R., V. V. Sree Narayan and K. R. Swaminathan 1996. Effect of Knife Angle and Velocity on the Energy Required to Cut Cassava Tubers. *J. Agric. Eng. Res.* 64 (2): 99-102.

Wickens, G. E., & On wueme, I. C. (1979). The Tropical Tuber Crops: Yams, Cassava, Sweet Potato andCocoyams.KewBulletin,34(2),418.https://doi.org/10.2307/4110008.

Yadav R., S. Pund. Patel N.C and L.P. Gite. 2010. "Analytical Study of Strength Parameters of Indian Farm Workers and its Implication in Equipment Design". *Agric Eng Int: CIGR J.* 12(2): 49-54.