INVESTIGATIONS ON DESIGN PARAMETERS FOR THE DEVELOPMENT OF A PINEAPPLE HARVESTER

By

ATHIRA PRASAD

(2016-18-007)

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY, TAVANUR – 679573

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DECLARATION

I, hereby declare that this thesis entitled **"INVESTIGATIONS ON DESIGN PARAMETERS FOR THE DEVELOPMENT OF A PINEAPPLE HARVESTER"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Tavanur

Date**:**

ATHIRA PRASAD

(2016-18-007)

CERTIFICATE

Certified that this thesis entitled **“INVESTIGATIONS ON DESIGN PARAMETERS FOR THE DEVELOPMENT OF A PINEAPPLE HARVESTER”** is a bonafide record of research work done independently by Ms. Athira Prasad under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Place: Tavanur

Date:

Er. Shivaji K. P.
(Major Advisor, Advisory Committee)
Assistant Professor
Department of FMPE
KCAET, Tavanur

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LIST OF SYMBOLS AND ABBREVATIONS

APEDA	: Agricultural & Processed Food Products Export Development Authority
ARDS	: Action for Rural Development Society
ASABE	: American Society of Agricultural and Biological Engineers
d	: Diameter of stem
DES	: Department of Economic Survey
E	: Cutting Energy
et al.	: And others
etc.	: Etcetera
Fmax	: Maximum Cutting Force
FAO	: Food and Agriculture Organisation of the United Nations
GI	: Geographical Indication
ha	: Hectare
hp	: Horse power
ISHS	: International Society for Horticultural Science
KAU	: Kerala Agricultural University
KCAET	: Kelappaji College of Agricultural Engineering and Technology
KVK	: Krishi Vigyan Kendra
min	: Minute
MT	: Million tonne

n.d	: no date
NGO	: Non-Governmental Organization
nos.	: Numbers
PALF	: Pineapple leaf fibre
t	: Tonnes
TNAU	: Tamil Nadu Agricultural University
w.b	: Wet Basis
WTO	: World Trade Organization

Introduction

CHAPTER I
INTRODUCTION

Agriculture is the substantial sector across the globe that perpetuates the lives on earth. With the exponential population growth, agricultural sector is working hard to satisfy the food needs and nutrient requirement of the world. It is projected that in 2030 the crop output should be 70% higher than current output. Fruits and vegetables will play major role in feeding populations in both developed and developing countries (FAO, 2018). India is the second largest producer of fruits and vegetables (APEDA, 2018). Mango, pineapple, banana, pomegranate, grapes, are the major fruits that account for larger portion of fruits production and export from the country.

The pineapple (*Ananas comosus*) is a tropical fruit with significant economical importance. Pineapple having excellent juiciness, flavour and remarkable health benefits, can be consumed either fresh, canned or in various processed forms. Pineapples contribute over 20% of the world production of tropical fruits. The global market of pineapple had a greater growth for the last decade with an increment from 1.38 MT in 2010 to 1.96 MT in 2016. India ranked fourth in the world production of pineapple with a production of 1.96 MT in the year 2016 (FAO, 2018). The total area under pineapple cultivation in India was about 11000 ha in the year 2015-16 (FAO, 2018). Pineapple cultivation in India is dispersed through the states of Assam, Karnataka, Kerala, Meghalaya, and West Bengal.

The area under pineapple cultivation in Kerala was 8,045 ha in the year 2016-17, with Ernakulum district ranking the top with 57.95% (GOK, 2017). Vazhakulam area of Ernakulam district is best suited for the cultivation of pineapple. Pineapple from Vazhakulam area of Ernakulam district bagged the GI tag under WTO guidelines (GI No. 130).

'Kew' and 'Mauritius' are the main varieties of pineapple grown in Kerala. For large-scale commercial cultivation, Kew variety is recommended. Mauritius variety is having better fruit quality and transportability and hence it is more acceptable for long-distance trade.

Pineapple cultivation is commonly practiced in humid tropics. Generally, pineapple is cultivated as an intercrop in rubber and coconut plantations or as a pure crop. Intercropping helps the farmer to get an additional profit during the long gestation period of rubber (Joy, 2010b).

In Kerala, farm mechanisation in the field of pineapple cultivation is in an emerging stage. Usually farm operations like Planting, intercultural operations and harvesting of pineapples are done manually. Among which, harvesting of pineapple is a tedious process. Fruit in the centre of a mature plant is harvested by breaking or cutting the fruit stalk with a clean cut of a knife. The foliar coverage of a single plant ranges between 1 to 1.5 m, it covers the inter space between the rows, which affects the movement of worker while harvesting. The growth of suckers in each year makes the plant denser, which makes harvesting more difficult. The workers should wear gloves in order to protect them from the sharp spines on the edges of pineapple leaves while harvesting, which creates inconvenience.

Manual harvesting of individual fruits is labour intensive and creates more drudgery to the workers. Manual harvesting of pineapple requires 11 man hours per hectare. Most of pineapple cultivation in Kerala is concentrated in hilly areas. The open working environment under the sun with high relative humidity and temperature make harvesting of pineapples extremely difficult. Reluctance of people to work in such conditions, unavailability of labours and high labour costs are the major crisis in this sector. Therefore, mechanisation of pineapple harvesting is inevitable.

A study on the pineapple harvesting using brush cutter was undertaken at Kelappaji College of Agricultural Engineering and Technology in the year 2015-16 and a pineapple harvesting attachment to brush cutter was developed and tested. Brush cutter was selected as the prime mover as it is a commonly used garden tool and attachments suitable for harvesting paddy and sugarcane have already been developed and are used by farmers.

In this attachment a 25 cm diameter circular blade replaced the hub or the lower part of the brush cutter shaft. The developed pineapple harvesting attachment was tested and evaluated under field conditions. It was found working satisfactorily especially for first year crops. The long handle permits the operator to operate the trimmer from a distance. Being simple in operation and light in weight it can be carried to field and can be operated with ease. Availability of small and light machine makes it suitable for women also. The major problem identified with the attachment, was the difficulty to move towards fruit for the second and third year crops due to the dense nature of plant (Prasad *et al*., 2016).

Basic information on its cultivation practices and evaluations on physical and mechanical properties of a crop is essential for the design and development of its machinery. It will also aid in the optimisation of final design. Cutting energy and cutting force requirement are some of the vital information in the design aspects of mechanical harvester. Hence, it is regarded to conduct a study on the physical and mechanical properties of pineapple plant and fruit. Considering all these into account, this study is focused on the investigation on design parameters for the development of a pineapple harvester and evaluation of different fruit holder designs suitable for brush cutter. Hence, this work was undertaken with the following objectives:

1. To study the physical and mechanical properties of pineapple plant and fruit, which influences the mechanical harvesting
2. To evaluate the performance of the existing pineapple harvesting attachment to brush cutter with different types of fruit holders and cutting mechanism
3. To optimise the design and to develop a prototype

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter includes the reviews on origin, cultivation practices and harvesting methods of pineapple crop and plant. Research works carried out for the mechanical harvesting of pineapple and similar fruits are also discussed in this chapter. Brush cutters and its attachment for harvesting different crops, estimation of cutting energy and force for cutting plant materials were reviewed in this chapter.

2.1. PINEAPPLE - ORIGIN

Tupi-Guarani Indians carried pineapples from its native place Paraguay and Southern Brazil to Mexico, West Indies, South and Central America (Radha and Mathew, 2007). Pineapples were spotted in the year 1493 at Guadeloupe, America by explorer Columbus and his colleagues; as reported by Collins, 1949. The capability of pineapples to tolerate draught and manageable transportation of suckers for replanting made the pineapples to diffuse around the globe. On the other hand, perishable nature of pineapples intricate its commercial trade in early centauries (Thevet, 1557; Acosta, 1590; Loudon, 1822 cited by Kenneth *et al.*, 2003).

In the early 16th century, pineapples were introduced in Philippines and then to Hawaii by Spaniards. It is believed that the plant was taken to India by 1548 by Portuguese traders from Moluccas. The plant is introduced to China and South Africa by 1594 and 1655 respectively (Radha and Mathew, 2007). Glimartin and Brown, 1987 states that pineapple cultivation was described for the first time by Charles Plumier at the end of 17th century on the Hispaniola Island of West Indies. Europeans started to cultivate pineapple in 1712, even though the fruit was introduced by 1650 (Radha and Mathew, 2007). Loudon, (1822) cited by Kenneth *et al.* (2003) reported that fresh pineapples were transported from Brazil to Europe during the early 19th century leading to a drop in greenhouse pineapple cultivation in Europe. In 1838, Lutheran missionaries took the plant to Australia from India (Radha and Mathew, 2007). Commercialised trade commenced at the mid of 19th century. The commercial processing of pineapple initialised in Hawaii in the late 19th century.

After the independence, government of India gave limited support to the pineapple cultivation until 1990. The first initiative in pineapple sector was in 1990, until the government did not recognize importance of pineapple as a core agricultural area. Presently, India contributes a major share in global pineapple production (Anon., n.d).

2.2. TAXONOMY AND MORPHOLOGY

Kenneth *et al.* (2003) described pineapple as one of the most economically valued crops in the *Bromeliaceae* family. Pineapple is scientifically termed as *Ananas comosus* and falls in the *Bromelioidea* subfamily, which is greatly diverse in nature. The family consists of plants with stiff and narrow leaves forming a cluster, short stems, and terminal inflorescence. The scale like multi-cellular hairs, coiled stigmas and star shape makes pineapple differ from monocots (Glimartin and Brown, 1987).

A mature pineapple plant has 1-2 m height and 1-2 m width arranged in a spinning top shape (d'Eeckenbrugge and Leal, 2003). The major morphological parts of pineapple plant include leaves, stem, crown, penduncle, roots and shoots (Hossain, 2016).

The pineapple is a biennial plant with a cluster of long leaves with parallel veins. The pineapple leaves may have spines along its periphery and may not have spines, based on their varieties. The length of pineapple leaves are ranging from 76 to 102 cm and width 5-7 cm. The closely growing leaves overlap each other at their base to form a flower-forming meristem. Usually every 13^{th} leaf is directly above another leaf lower down and there are 5 spirals between the 2 leaves that are in line. The number of leaves in a mature plant varies from 40 to 80. The older leaves are at the lower position and are short in length (5-20 cm), whereas the younger leaves will grow more than 160 cm long and 7 cm wide. The leaves are broader at the base, and pointed at the tip. The leaf is curved upwards on the side facing the stem. The back of the leaf is rounded. The leaves are semi rigid in nature (Collins, 1949; d'Eeckenbrugge and Leal, 2003; Elfick, 2007).

The largest and most recent leaf to mature is called the "D leaf". This is the highest leaf on the plant and it stands nearly straight up. The ‘D’ leaf is always easy to pull from the plant and leaf margins of this leaves are more-or-less parallel to the leaf base. Mature (‘C’) leaves are difficult to pull from the plant and have basal margins that are much wider than the margins of the upper part of the leaf. The margin of immature (‘F’) leaves taper inward at the base. ‘D’ leaves grows progressively along with the plant and it becomes longer and heavier. It was estimated that weight or length of leaf could be used to evaluate the growth of plant. It can also be used to determine time of artificial flower induction of plants to get the targeted weight of fruits (ISHS, 2008).

The club-shaped stem is 25-50 cm long, 2-5 cm bottom width, and 5-8 cm top width (d'Eeckenbrugge and Leal, 2003). The stem diameter had a direct influence on pineapple yield. Pineapple with large stem diameter has broad leaves and large fruit diameter, which has high yield and vice versa.

Pineapple is a herbaceous perennial, with inflorescence at the terminal (d'Eeckenbrugge and Leal, 2003). The inflorescence and peduncle were born on the apical meristem (Hossain, 2016). The borne of the inflorescence ceases the length growth of the plant (Collins, 1949). The spirally arranged inflorescence consists of 50 individual flowers to more than 200 individual flower based on the cultivars. The flower consists of both female and male reproductive organs. At the base part, the petals are white in colour, and at the tip, they are violet-blue in colour. The flower is tongue-shaped. The narrow compact tubular style arrangement of flowers permits only insects to access in to it. The sepals have a triangular shape (Hossain, 2016).

The plant bears a single fruit at the tip of a peduncle extended out from the centre of the plant (Joy, 2010b). The flowering process can induce artificially. The fruit will mature within time span of six to eight months (Collins, 1949). The fruit peduncles grow very rapidly until it reached its maximum size 7 weeks after induction treatment. At this stage, the crown begins to grow rapidly until harvest (Teisson, 1973). The fruit is cylindrical in shape with an average diameter of 8.11 cm and an average weight of 2.5 kg (Medina and Garcia, 2005). The weight of fruit increased in a sigmoid pattern. The weight of fruit was more in the summer season followed by the winter and rainy season. The length and diameter of fruit continuously increase until the maturity stage. Fruit shapes significantly vary with the growing season. In summer, season the percentage of conical and cylindrical fruits dominates, while the percentage of spherical fruits dominates in the winter and rainy seasons (Joomwong and Sornsrivichai, 2005).

The pineapple plant has an adventitious root system. Most of the roots come from the bottom of the stem or butt. Other roots often grow from the axillary buds of the lowest leaves. These roots are called axillary roots under normal conditions, root system spread laterally up to 1-2 m and up to 0.85 m in depth. The growth of root system commences immediately after planting and terminates until flowering. The spirally arranged pineapple leaves forms a dense compact rosette (d'Eeckenbrugge and Leal, 2003; Elfick, 2007; Hossain, 2016).

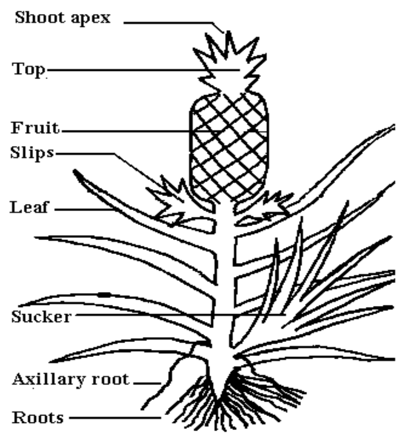


Figure 2.1 Parts of pineapple plant (Elfick, 2007)

2.3. PROPERTIES OF PINEAPPLE STEM AND LEAVES

Joy (2010a) states different benefits of pineapple including its anti-inflammatory benefits, digestive benefits, immune support, anti-oxidant protection, health benefits, food uses, and fibre content. The pineapple stem and leaves contains white, silky strong fiber, which have a number of versatile applications.

Zainuddin *et al.* (2014) determined the physicochemical properties of pineapple leaves and stems of pineapple residue. The thermogravimetric analyser was used to measure liginin, hemicellulose, and cellulose content. The crude fibre content in the leaves was 37.63-31.04% and the same in stem was 37.63-41.75%. The study concluded that the stem and leaves of various varieties exhibited different liginin, hemicellulose, and cellulose content.

Daud *et al.* (2014) analysed the chemical compositions of pineapple leaves and investigated the morphology of pineapple leaf fiber. The study concluded that pineapple leaves had 85.7% holocellulose, 66.2% cellulose, 19.5% hemicellulose, and 4.2% lignin content. The pineapple leaf had a high moisture content of 81.6%.

Asim *et al.* (2015) conducted a study on the pineapple leaf fibre. The fibre is smooth, white in colour, glossy, medium length with high tensile strength. Pineapple leaf fibre (PALF) had a soft surface than any other natural fibre. The PALF contained 70-82% of alpha cellulose. The high cellulose content in the leaf fibre improved its specific strength, stiffness, and added to the weight of fruit. It is hydrophilic in nature. A fresh leaf contained about 2-3% of fibre. PALF improves the mechanical, dielectric, and elastic properties of the leaves.

2.4. CULTIVATION OF PINEAPPLE

The major aspect of pineapple cultivation is the preparation of ground. The minimum depth of ploughing for pineapple cultivation is 30 cm. The common planting practice adopted is beds with controlled slope (0.3 to 0.5%). The bed width varies based on the density of plants and row spacing, ranges between 110-145 cm. Weed growths is one of the major competency factors, and hence it should be eliminated either manually or by the application of herbicides. Fertilizer application is done four times in each vegetative cycle. Hormones like Ethrel or Calcium carbide are used for artificial flowering. Ethephon, active ingredient of Ethrel is used at a rate of 1-1.5 ml per litre of water, 18.14 g urea per litre of water, and 4 litre of Boron for the artificial flower induction. The growing period of pineapple varies on climatic conditions and location. It is nearly 12 month on the equatorial regions and the same can extend up to 36 months in sub-tropical area. Under normal conditions, crown, slips, and suckers requires approximately 23, 20, 17 months respectively to produce a new fruit (Medina and Garcia, 2005).

Hotegni *et al*. (2012) investigated on pruning slips of pineapple on selected plants to reduce the heterogeneity in pineapple there by encouraging the fruit growth on those plants. The side shoots, which are developed just beneath the fruit during its growth, are termed as slips. The quality of fruits and its variation are independent of the time of pruning and number of plants pruned. The development of slip along with the fruit may result in competition for available nutrients within a plant leading to the reduction in fruit quality.

2.4.1. Factors Influening Pineapple Cultivation

Different factors including location, soil type, rainfall, temperature, drainage and nutrient can influence the development and production of pineapple plants.

(i)Location

Pineapple can grow between 31º N and 34º S, in the humid hill slopes with mild tropical climate. It can grow at low elevations either as an intercrop in coconut and rubber plantations or as a pure plantation scale crop. For the intercropping cultivation of pineapple ideal elevation of the location ranges from 500-700 m (TNAU, 2014; FAO, 2018).

(ii) Soil and pH

Pineapple can be grown in broad varieties of soil. Acidic soil rich in organic matter and potassium is suitable for pineapple cultivation. The ideal soil for its cultivation is sandy loam textured soil. A light well-drained soil with pH ranging from 4.5 to 6.5 is suitable for the pineapple cultivation. Heavy soil provided with adequate drainage facilities can also be prefered for pineapple cultivation. The soil should have less lime content (KAU, 2011; Hossain, 2016; FAO, 2018).

(iii) Temperature

The temperature range for the good growth of pineapple cultivation is between 22ºC to 30ºC, with an optimum of 23ºC to 24ºC. A suitable combination of optimum temperature and high humidity can yield high quality fruits. Pineapples are not able to withstand water logging conditions (FAO, 2018).

(iv) Rainfall

Pineapple cultivation can be practiced in expansive range of rainfall from 600-2500 mm per annum; the optimum range being 1000 to 1500 mm per annum. May-June is the ideal planting season for pineapple. The planting should be avoided during the heavy raining periods (KAU, 2011).

2.4.2 Vegetative Propagation of Pineapple

The propagation of pineapple can be done by three vegetative methods viz, crown on the top of fruit, the suckers borne from the leaf axles of the main stem, and the slips grown on the peduncle below the fruit. After fruiting, the separated suckers from the plant are dried to prevent rotting. The planting arrangement in the field varies across the world depending on the customs and local conditions. The planting should be done in two-line beds leaving enough spaces permitting intercultural operations. It was reported that the number of plants per unit area is largely influencing the yield and the planting is done in such a way that, the first crop yields about 32 tonnes per acre and the first ratoon yields 20-25 tonnes (Collins, 1949). Moreover, these should be select properly for the crop uniformity (Medina and Garcia, 2005).

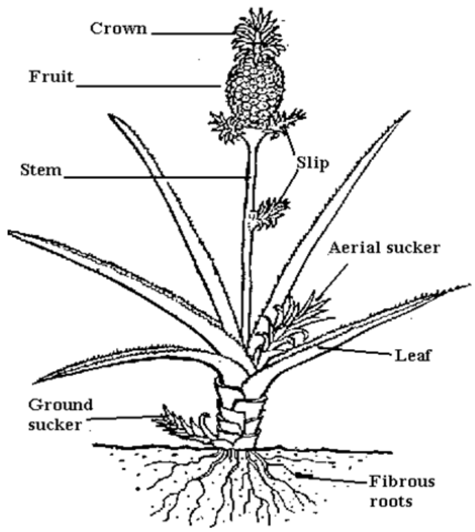


Figure 2.2 Vegetative propagules of pineapple (Elfick, 2007)

The growth of new suckers from the auxillary buds, after the maturation of first fruit, is efficient to produce new inflorescence, which transform to fruit. Hence, a single plant is capable of giving a sequence of production cycle (d'Eeckenbrugge and Leal, 2003). The size of fruit reduces with the consecutive years.

The crown of the fruit is morphologically similar like the vegetative leaf and its growth follows a sigmoid pattern, and its length increases about 30-45 days after the commencement of the fruit growth. The fruit may have multiple crowns or no crowns (Teisson, 1973; Joomwong and Sornsrivichai, 2005).

Slips are fundamental fruit with embellished crown (Hossain, 2016). They are borne on the axial bud on the peduncle of fruit and became visible when the fruit is half developed (Medina and Garcia, 2005; Hossain, 2016).

5. PINEAPPLE CULTIVATION IN KERALA

Pineapple cultivation in Kerala is generally practiced as an intercrop in the first three years of rubber plantation in small land holdings. Of the total cultivated area in the state, rubber holds a major share. Rubber has around seven years of gestation period during which adoption of a commercial crop like pineapple as an intercrop can add to the profit. After considering various factors associated with the pineapple cultivation including the land rent, capital productivity and marketing, pineapple as an intercrop in the first three years of rubber plantation was considered more economical than any other crops. The marketing and processing of pineapple are considered to be inadequate. Pineapple leaves also has a potential profitability as raw material for fibre production (Rajasekharan, 1989; Rajasekharan and Veeraputhran, 2002).

The planting method adopted in the state is in paired rows, with a spacing of 45 cm between the rows and 30 cm between the suckers. 120-150 cm of interspacing is provided between the paired rows. A plant is usually replaced after the third harvest in commercial cultivation of pineapple. In the first year of cropping, fruit is harvested from the mother plant and in successive years, fruits are harvested from the suckers (Collins, 1949; KAU, 2011).

Kew and Mauritius are the two main varieties cultivated in Kerala. Kew variety is suggested for value addition and processing. Mauritius variety is regarded as the best in quality, flavour, sweetness, and aroma. Hence, it is suggested for commercial cultivation in Kerala for table purpose and distant marketing. It is cultivated in Ernakulam, Kottayam, Pathanamthitta, and Idukki districts of Kerala (Joy, 2010b).

5. HARVESTING OF PINEAPPLE

Collins (1949) described that the pineapple plant will be ready for harvesting within 15 to 22 month of planting in Hawaii regions. The harvesting time is greatly depending on the type of planting material. The crown fruit requires 22 months to harvest the fruit after planting, the slips fruit requires 18-20 months whereas the sucker fruits will be ready for picking after 15 months of planting. Approximately one year later of the harvesting of first fruit, the same plant can give another fruit and this is termed as first ratoon crop. The first ratoon crop was borne on the suckers of the mother plant. Similarly, the second ratoon can be obtained if the plant remains healthy.

The harvesting maturity of pineapple depends on the final use of fruit. Pineapples should be picked at the light yellow colour of flesh and tender, for canning and for consumption as fresh fruit. Green chloroplasts in the spongy tissue and a pink colouration in the cells beneath the epidermis are observed under a microscopic study of sepal cross section from an unripe fruit. When the fruit ripens, pink colour fades and the chloroplasts changes to yellow colour (Huang *et al.*, 1960).

d'Eeckenbrugge and Leal, (2003) described that in commercial cultivation single plant is only allowed to yield two or three fruits. Further yield from the same plant will reduce the uniformity and size of fruits.

Joomwong and Sornsrivichai, (2005) studied on the quality of pineapple harvested in different seasons. The fruit would be ready for harvesting after 110-160 days of full bloom. The prime factor affecting the fruit growth was temperature. The maturing period of winter crop is 30 days slower than the summer crops. The winter crops are harvested at the stage in which there is a slight or pale yellow colour in the base and they have sour flavour. The rainy and summer crops are yellow in colour and sweet flavour.

According to Medina and Garcia (2005), Harvesting of pineapple is done 5 month after the flower induction. The harvesting stage changes depending on the distance to market, colour preference by the buyer, and required export quality etc. The fruits are ready to harvest when the colour turns to golden yellow, and handled carefully to avoid mechanical damage. The harvesting is done with special knife or devices to separate the fruit from the plant. Then the fruits are carried to the trucks pacing the crown downwards for cushioning.

6. MECHANICAL HARVESTING OF FRUITS

O'brien *et al.* (1970) studied the possibility of mechanical harvesting of pineapple. The study concluded that by mechanical harvesting of pineapple, the crop losses would be 2.5 times and it would increase the cost of operation. He suggested that the mechanical harvesting of pineapple can be made economical by adopting modified cultural practices.

Gaillard (1978) studied on the mechanical harvesting of pineapple and orchards. According to him, mechanical pineapple harvesting is restricted to the conveyor belts, and this method is economic for large plantations only.

Rosa (1990) developed a semi-mechanised harvesting machine for pineapple named as SAP-36. The harvester used in Cuba, can harvest pineapple either with crown or without crown. The machine had theoretical productivity of 24 t/h and the operating cost could be reduced up to 3.27 pesos/t (rupees 11.35/t).

Soon (1992) developed a cutter powered by hydraulics for the mechanical harvesting of fruits such as banana, pineapple, and oil palm. The operation of developed hydraulic harvester could be done either by a gear pump or by a hand pump. The harvester consisted of an extendable long aluminum pole to which the cutting blades are attached. A ram operated the cutting blades. The other end of aluminum pole was connected to a pump. Suitable operating mechanism and blade were identified by conducting both field investigations and laboratory tests. The cutter weighed 12 kg with engine driven pump attached and 6 kg with the hand-pump.

Bakhtiari *et al.* (2013) investigated on fruit picking mechanism and conducted the field experiments. A prototype model was designed and fabricated and its cost effectiveness and efficiency were determined experimentally. The experimental results concluded that the proposed mechanism worked satisfactorily with a good level of accuracy. The evaluation was conducted in 210 fruits of which 9% were damaged.

7. BRUSH CUTTER AND HARVESTING ATTACHMENTS ON BRUSH CUTTER

Yadav *et al.,* (n.d.) developed an ultraportable cutter for harvesting various crops including grass, rice, cane etc. The cutter consists of two-stroke petrol engine of 1.2 kW power, fuel tank, air cleaner, recoil starter handle, drive shaft assembly, front handle, and nylon cutter head. The ultraportable cutter tested in field for grass cutting and rice harvesting. The harvesting of crops using the developed cutter required 5-6 hours to harvest an area of 1 acre with one skilled labour thereby saving of cost and time by 80%. The portable cutter was easy to fabricate, light in weight and low cost.

Langton *et al.* (2006) modified a brush cutter to a sugarcane harvester (Ilovo mechanical cane cutter), which suited to the steep slope areas of South Africa. The developed harvester was evaluated in the field. The average output of the harvester was 2.5 t/h with a downtime of 42%. The Illovo mechanical harvester consumed more energy compared to manual harvesting but could reduce the drudgery in operation and increase cane cutter performance.

Bora and Hansen (2007) studied on developed a mechanical rice harvester suitable for small land holdings, which can harvest rice at low cost, by modifying a brush cutter. The modifications included the replacement of brush cutter blade by a circular saw blade of 25 cm diameter. To guide the harvested stalks to the left side a rubber guard and a metal plate assembly were fitted on the handle, behind the blade. The machine performance was evaluated in the field conditions and results showed that the harvester has about 0.51 ha/day field capacity and 0.25 l/h fuel consumption. Although the harvester was 7.5 times faster than manual harvesting, the field loss was 2.3% against 1% in manual harvesting. The break-even area was 1 ha and with one year payback period. The machine was well suitable for low-income farmers in developing countries, and women.

Reddy *et al.* (2010) designed and fabricated a petrol operated nylon treaded trimming device to improve the operators comfort suitable for Indian scenario. The trimmer consisted of a trimming head system made of workshop scrap materials, drive shaft spindle, and bushed sleeve. To reduce fatigue of operator, the optimum position of handle for different length of cutting thread and speed of the engine were determined. Compared with the engine speed, the length of nylon thread in three handle positions had more influence on the hand vibrations. The result concluded that the optimum values of operating parameters are 20 cm long nylon thread. An engine speed of 3300 rpm was seems to have minimum hand vibration. The engine noise was reduced by 6 dB by providing an additional muffler at the exhaust. The fuel consumption rate with nylon thread was 22% lower than the trimming operations using metallic cutter.

Handaka and Pitoyo (2011) conducted a research on the suitability of a rice harvester attachment to a brush cutter/grass cutter. The aim of the study was to provide simple harvesting machinery for multi-cereal commodities, which is light in weight, easy to operate, and has a large capacity. In the study, they selected a straight type lawn mower. The modifications provided are replacing the cutting blade by circular blades of 255 mm diameter, adding a guider and a driving force to drive the cutting, and adding an operator belt for easy operation. The rotation speed was 3000-4000 rpm. The performance test for the rice harvester was conducted with a theoretical work width of 75-100 cm (3-4 lines) and the work capacity was obtained as 18.54-26.3 $h.ha^{-1}$, with a fuel consumption of 0.60 - 0.86 $l.ha^{-1}$.

A pineapple harvester suitable for harvesting pineapples in the hilly slopping areas of northeastern hill regions was developed. The manually operated harvester consists of a 1.5 hp petrol engine, 1500 m long and 30 mm diameter mild steel rod. To the one end of long rod, petrol engine was attached, while at the other end a cutting blade of 125 mm diameter was attached. As the rotating blade cuts the pineapple stalks, the finger provided above the cutting blade held the pineapple. The harvested pineapple was then shifted safely to the basket on the ground. The machine weighed about 9 kg. The machine was suitable to harvest 250-280 pineapple fruits per hour with an efficiency of 70.44%. The estimated cost of operation was 1.5 rupees per fruit harvested (Dixit *et al*., 2015).

8. CUTTING ENERGY AND CUTTING FORCE

McNulty *et al*. (1980) studied the impact cutting of grass to determine the physical and mechanical properties of the forage in relation to the maturity, dry matter, and size. A shear test rig was employed for cutting the forage stems and leaves in a double shearing process. The study concluded that the mechanical properties have a significant effect on the dry matter and independent of shear velocity excluding the stem resistance to penetration. The resistance to penetration was influenced by the bevel angle of the blade.

Kushwaha *et al.* (1983) modified the shearing apparatus, which has been used to determine the shear strength of soil to measure the shear strength of wheat straw. A strain gauge load cell was employed for the measurement of shear force of the straw. The study concluded that the shear strength and moisture content had a non-linear relationship at two phases, initially at the increasing stage and then at the constant stage. The shear was easier at the low moisture contents, due to the viscoelastic nature and brittleness. The most efficient shearing of the straw occurred at 8% and 10% moisture levels. The shear strength was found to be independent of the shear velocity. The increased blade sharpness resulted in the lowering of cutting energy.

O'Dogherty and Gale (1991) conducted laboratory studies on grass cutting to deduce the impact of stem configuration and blade characteristics on cutting. The experiments were carried out for different speeds varying from 15 to 35 m/s and rake angle of the blade was varied from 0º to 45º. The blades with blunt and sharp cutting edges are employed in the laboratory tests. At critical speed, the blade rake angle and blunt blades were found insignificant on the force and energy required for cutting. While at lower speeds, increased blade angle left more number of stems uncut. The sharpest blade with 0.325 mm thickness required half of the specific force and 1/3 rd of the specific cutting energy than that of the most blunted blade having 0.15 mm thickness. The critical speed was independent on the number stems in the group and the configuration.

Jelani *et al*. (1998) investigated the importance of specific cutting force and specific enrgy requirement in the design of a cutting system. Sickle cutter and claw cutter are two designs on which the study focused. The maximum values of specific force and energy was 12.2 kg/cm^2 and 65.4 kg-cm/cm^2 respectively for the sickle cutter. In addition, the same for claw cutters are 22.9 kg/cm^2 and 115.5 kg-cm/cm^2 respectively. The results concluded that the sickle cutter demanded 47% less specific force and 76.5% less specific energy in comparison with the claw cutter.

Ranganna *et al*. (1995) studied the mechanical properties of paddy to aid in the design of vertical conveyor reaper. The static and dynamic forces were determined with the help of suitably designed test rigs. The results showed that the dynamic cutting force was directly related to the cross-sectional area of stem and reversely related to the moisture content.

Aranwela *et al*. (1999) studied the methods of assessing leaf-fracture properties. They conducted three mechanical tests including punching, tearing, and shearing, to determine the influence of various test factors on the fracture properties. The parameters considered for the punch and die test were clearance between the punch and die, area of punch, speed, and punch edge definition. Aspects considered for the shearing test are sharpness, angle, and effects of blade proximity. For the tearing test, the parameters included are length- width requirements of the test strip, end effects and length of the notch. Among the tests, shearing and punching tests were found to be beneficial for the leaf fracture assessment.

Yiljep and Mohammed (2005) studied the influence of velocity of knife on the energy required for the cutting of sorghum stalk. In the study, they designed and fabricated a laboratory test-rig similar to izod impact cutting machine for metals for the measurement of cutting energy and cutting efficiency. The test-rig consist of frame, swinging arm, weights holder, stalk holder and an angle indicator. Cutting energy requirement had a negative effect on the knife weight and stalk moisture content, whereas the cutting efficiency had a positive effect on the same. The minimum energy requirements at knife velocities 2.91 and 3.54 m/s for 20 and 120 mm diameters were 7.87 and 12.55 Nm respectively. At 5.2 and 7.3 m/s knife velocities, maximum-cutting efficiencies had been observed as 98 and 97% respectively.

Koloor and Borgheie in 2006 designed and fabricated a static and dynamic shear apparatus to measure the cutting force of rice stems. They selected four varieties of Iranian rice varieties. The static shear test unit comprise of stem holder, stand, cutter bar, blade section, regulator, frictionless pulley, and loading tanks. A constant increase in the static load of 10 cm^3/s was maintained with the help of regulator. The shear strength was determined by taking the ratio of force and cross-sectional area. The study concluded that the cutting force has a linear relationship with the cross-sectional area and a non-linear relation with moisture content. The shearing strength of the stem was independent of the blade type and bevel angle.

Ghahraei *et al.* (2008) developed a sweet sorghum harvester, which consisted of a 50 cm diameter rotary disk and four cutting blades. The cutting of stem takes place due to the impact and inertia forces provided by the cutting blades at 27 m/s linear velocity. In designing the cutting system, the maximum cutting force requirement of sweet sorghum was considered as same as the cutting force requirement of maize stem with 87% moisture level. The energy requirement of the system was then determined by calculating the area under the graph plotted between cutting force and movement of blade through stem diameter given by Persson, 1987. The results concluded that the blade penetration and smooth cutting surface was obtained with 30º angle blade than 45º angle blade.

Tavakoli *et al.* (2009) compared the mechanical properties of barley and wheat straw. The study conducted shearing test and bending test of the samples for three inter node positions down from the ear and two moisture levels (10.24% and 10.76%). The moisture content of the samples were determined by drying the samples in oven for 24 h at 103ºC (ASABE, 2006) and then reweighed. The results concluded that the specific shearing energy of both barley and wheat straw was increases towards the third inter node position. Young's modulus and bending stress were found increases towards the first inter node position. The average shear strength of barley straw varied from 3.90 to 4.49 MPa and the same for wheat straw was varied from 6.81 to 7.12 MPa.

Dange *et al*. (2011) investigated the cutting energy and fore required for the pigeon pea stems. A pendulum type dynamic tester was fabricated to study the cutting force in a laboratory. The study was conducted with four independent physical parameters, which were stem diameter, moisture content, and speed and bevel angle of the blade, with three replications. The physical parameters were calculated based on standard procedures. The experiment concluded that the stem with 8 mm diameter required minimum energy (17.38 Nm), the stem with 30 mm diameter requires maximum energy (141.96 Nm), and the respective forces required for cutting were 232.5 N and 747.3 N. The moisture content had a negative effect on cutting energy and force up to 45% moisture content, and thereafter showed positive effect as moisture content increased. As the stem diameter increased, cutting energy and force also increased. The blade with bevel angle 30º performed better than blade with 45º bevel angle.

Dange *et al*. (2012) determined the cutting force and energy of the pigeon pea stem to aid in the design procedures of a tractor mounted cutter for pigeon pea stems. For determining the cutting force and cutting energy, a pendulum type impact tester was designed and fabricated. The sample of 30 mm diameter with 42.6% moisture content (w.b) requires 747.25 N cutting force and 14.96 Nm cutting energy when it is cut by a blade with a bevel angle of 30º. The study concluded that the cutting force and energy are directly related to; harvesting time, moisture level, and the cross-sectional area.

Baneh *et al.* (2012) designed a cutting head suitable for brush cutter to develop portable harvester for rice. Cutting head consisted of 24 cm diameter circular blade. The cutting and power requirement of the system was determined based on the diagram plotted between cutting force and movement of blade through stalk diameter. From the results, it was concluded that field capacity of portable harvester was 4.20 times greater than the manual harvesting.

Heidari *et al*. (2012) researched on the mechanical and physical properties of Lilium stalk with the help of a universal testing machine. Physical properties considered in the study are size, weight of the specimen, density of stalk, and moisture content. Mechanical properties considered are the shear strength, compression strength, bending and modulus of elasticity. The experiments were conducted for three loading rates (30-50 mm/min) and for the three bevel angles (30º-60º) and conclude that all the factors considered have significant influence on the mechanical properties. The lowest values of specific compression energy and compression energy were found at the upper level and vice versa. The loading rate was inversely related to the bending strength. In all loading conditions, the specific cutting energy and shear strength are directly related to the knife bevel angle.

Hemmatian *et al.* (2012) investigated the physico-mechanical properties and energy requirements for the sugarcane stems, which was vital for the design of the appropriate knife. The moisture contents of the samples were determined by oven-dry method (103ºC for 24 hours). The sugarcane stems were evenly divided into 10 height sections with 10 nodes. The study employed a computer-assisted cutting apparatus. The values of specific shearing energy and shearing strength were observed to be higher in the lower section of the stem because of the structural diverseness. The specific shearing energy and the shearing strength increased 4.6 and 3.2%, respectively for an increase in shearing speed from 5 to 15 mm/min.

Johnson (2012) conducted a research on energy requirements and productivity of machinery used to harvest herbaceous energy crops. The energy required for cutting individual stems was quantified with the help of a high-speed cutting apparatus coupled with a data acquisition system. Based on the studies on the cutting of a single stem, the critical cutting speed at which the ideal cut quality obtained with minimum cutting energy was found. The cutting energy requirement of single stem (9.30 ± 2.60 J per stem) was only 2.1% of in-field mowing requirements. It concludes that, since single stem cutting requirement represents only a small percent of the net energy requirement, it would not contribute to power reduction.

Samaila *et al.* (2012) developed an apparatus to determine the energy requirement of a sugar cane harvester, which consists of a base support, frame, flange, crank, spindle, front hub, freewheel, chain, and sprocket. The experiments were carried out in the field and placed, as much near to the plant needs to be cut. The time taken for the 10 revolutions of the crank by manually was noted. Subsequently, after the 10^{th} revolution, the sugarcane plants were introduced. The cutting was done by the rotating blade and disc due to their inertial forces. The results showed that 23.83 J were required for the bottom part of sugarcane, whereas the top part requires 15.71 J.

Taghinezhad *et al*. (2013) researched on the significance of moisture content on cutting energy and cutting tool, and the dependency of cutting force, ultimate stress, energy, and specific energy on dimensional aspects. The study employed linear cutting blade and UTM. The experiments are formulated for three moisture levels viz, 50-75%, 10-50%, and 0-10%. The absolute moisture content of samples was determined by oven-dry method (103ºC for 24 hours). The experiments are conducted at 10 mm/min loading rate of UTM. The cutting and force were measured for the three levels of moisture contents. The dependency of mechanical strength factors with respect to the orientation, sample material, and the sample size are obtained with the aid of SPSS software (2007). The maximum specific cutting energy (34.071 N/mm) and maximum ultimate stress (7.086 MPa) was found at lower cutting moisture levels. The study concludes that high-level moisture contributes a significant reduction in the specific energy and ultimate stress.

Azadbakht *et al*. (2014) conducted a study for the determination of energy requirement for cutting corn stalks. A pendulum system was designed and fabricated, which works on the principle of conservation of energy. The system consists of beams, pivot axle, pendulum arm, blade, and finger. From the results obtained it is concluded that the maximum cutting energy was 3.22 kJ at 63% (wet basis) moisture content and the minimum energy was 1.63 kJ at 83.25% (wet basis) moisture content. The height, moisture content and their interaction have a significant effect on the cutting energy.

Dauda *et al*. (2014) determined the influence of moisture content on the mechanical and physical properties of Kenaf stems. Physical properties viz., stubble height, length and diameter of the Kenaf stems are measured using tape and vernier caliper. The moisture content was determined by oven-dry method by keeping the sample at 104ºC for 24 hours. The mechanical properties viz., compressive stress, cutting force, cutting energy, stem area, and Young's modulus where determined with a Universal Instron Testing Machine provided with a blade having an edge angle of 25º. The study concluded that at the maximum cutting force observed at 72% and 35% moisture contents were 1584.55 N and 694.86 N respectively and the maximum cutting energy obtained at 72% and 35% moisture contents were 8.75 J and 3.50 J respectively.

Azadbakht *et al*. (2015) determined the energy requirement of canola stem relevant to the cutting height and moisture content. A pendulum impact test device works on the principle of conservation of energy was designed and fabricated. The tests were repeated for 15 times for different height and moisture levels, and later analysed with the help of SAS (Statistical Analysis Software) and split plot design. The maximum value of cutting energy 1.1 kJ was observed at 25.5% (w.b) moisture content and 10 cm height of cutting, whereas the minimum value of cutting energy 0.76 kJ was found at 11.6% (w.b) and 30 cm height. The study concluded that the moisture content and height of cutting has significant effect on the cutting energy, but the interaction of both does not have any significant effect.

Mathanker *et al*. (2015) investigated the effect of blade oblique angle and cutting speed on cutting energy for energycane stems in 2015. The experimental arrangement included an air- cannon powered impact type cutting mechanism. The stems of energy canes cut close to the ground were taken and placed vertically in the arrangement. The oblique angles selected are 30, and 60º, in which the lowest average specific cutting energy (02.6 J/mm) was observed at 60º for an average cutting speed of 7.9 m/s. stem diameter and stem cross-sectional area showed a close correlation with specific cutting energy. From the study, it was concluded that, by selecting an appropriate blade oblique angle and cutting speed, the energy required for cutting could be reduced by a factor of five.

Sureshkumar and Jesudas (2015) studied the physical and mechanical properties of sugar cane stalks influencing the mechanical harvesting. The cutting energy measured using a pendulum type impact test rig. The kinetic energy transmits to the knife, the shearing resistance of stem, cutting length, and cutting blade sharpness are major factors determines the power requirement. The sugarcane stems from the bottom of the plant are collected and tests were conducted for different combinations of tilt and oblique angles in five replications. The results showed that the value of cutting energy was 27000 J/m^2- 37000 J/m^2 when the oblique angle was at zero degrees. The minimum values of cutting energy were observed at 15º -25º oblique angles and the minimum specific cutting energy was found at 20º tilt angle.

Deshmukh and Thakare (2016) attempted to study the shear strength of sorghum stalks. The samples from the lower, middle and upper section of the stalks of the three different varieties of sorghum stalks are collected and the moisture contents were determined based on the ASAE standard S.352 (ASAE year book 1979). Food Texture Analyser used for the experiments. The specimen placed on the rigid fixture on the base platform. The machine consists of a 250 Kg capacity load cell and a knife fixed to the crosshead. The selected speed range for the crosshead was 50-75 mm min^{-1}. The cutting stress, σ can be calculated using the following equation:

$$\sigma = \frac{F}{A}$$

$$\text{Specific shearing energy} = \frac{F}{A} \times \text{Travel of knife}$$

The mean cutting force for lower, middle and upper section at75 mm/min was 364.39 N and50 mm min^{-1} was 301.2 N. The specific shearing energy of the lower section of all three samples showed an increasing pattern.

Susilendra *et al.* (2016) determined the cutting energy and cutting force of chickpea stalks using a pendulum impact test apparatus. The collected chickpea stalks were held at the point of maximum kinetic energy. The experiment was carried out with two types of blade viz., serrated and smooth edge. The study analysed the influence of cutting blade on cutting energy, force ad specific energy. The result concluded that the cutting energy, force and specific energy requirement of blade with serrated cutting edge was less than the blade with smooth edge. The cutting velocity was inversely related to the factors considered.

9. GARRETT'S RANKIG METHOD

Zalkuwi *et al.* (2015) used the Garrett's ranking method to analysis the factors affecting the sorghum cultivation in India and Nigeria. The study identified the major constraints related to the sorghum cultivation. Then the farmers are allowed to rank the problems. The major advantage of this Garrett's ranking method was, it consists of arranging the constraints based on their importance from the respondent's point of view. The study concluded that low rice, inadequate agriculture credit, extension support and research, high input cost, shortage of input and variation in rainfall availability are the major issues faced by the sorghum farmers in India. Meanwhile, the issues handled by the farmers in Nigeria are inadequate credit, extension support and research, low price, cattle rearers, striga infestation, and high cost/shortage of input.

Balaganesh *et al.* (2016) analysed constraints related to the precision farming adoption of banana in Tamil Nadu using Garrett's ranking method. Five villages from the Chinnamanur block of Theni district were selected. From the selected five villages, 40 farmers involved in precision farming of banana and 40 farmers involved in conventional farming of banana were selected randomly and requested them to rank the selected constraints. The results revealed that the insufficient marketing facilities and power supply problems are the important infrastructural problems. Inadequate resource and technical expertise are the major constraints in the adoption of precision farming. High input cost, high installation cost of drip and fertigation system and the instability in price are the major economic issues faced by the banana farmers.

Nirmala *et al.* (2016) adopted Garret's ranking method to measure gap in rice yield on small farms and to find out factors contributing the gap. A total of 120 small rice farmers were selected and interviewed. The information on the demonstration yield and research yield were collected from the KVK offices and ARDS-NGO. The results showed that, shortage of labour, lack of remunerative cost, pest infestation, diseases, and unavailability of fertilisers are the major constraints in the field.

Materials and Methods

CHAPTER III
MATERIALS AND METHOD

This study was undertaken to investigate on the physical and mechanical properties of pineapple to aid in the design of mechanical harvester. An attempt was made to determine the cutting energy and cutting force requirements of pineapple stem and leaves by fabricating a field-testing apparatus. The study also includes the field evaluation of different designs of fruit holders suitable for brush cutter for harvesting pineapple. This chapter deals with the methodology adopted for the study.

3.1 PHYSICAL PROPERTIES

The physical properties of pineapple plant, stem, leaf and fruit were studied for the design of appropriate machineries required for pineapple cultivation and harvesting.

3.1.1 Plant

Physical properties of pineapple plant including the height of plant, number of leaves in a mature plant, height of fruit from ground, angle of inclination, number of suckers on a single plant, visible length of stem, and foliar coverage were recorded.

3.1.1.1 Planting Geometry

Planting geometry including plant density, spacing between the rows, suckers and between the paired rows were determined. The measurements were taken using standard tape.

Plate 3.1 A view of pineapple field

3.1.1.2 Height of Plant

Height of plant, which is the distance between the ground level and the tip of most protruding leaf, was measured using standard tape. The measurement was taken randomly in the field.

3.1.1.3 Number of Leaves in a Mature Plant

The number of leaves in a mature plant gives an indication of dense nature of plant. The number of leaves of randomly selected plants in the field were counted and recorded.

3.1.1.4 Height of Fruit from Ground

The process of harvesting pineapple using brush cutter depends on the height of fruit. The height was measured from the ground level to the top of peduncle using a steel rule. The measurements were taken randomly in the field.

3.1.1.5 Angle of Inclination of Fruit

Pineapple fruits are emerged on the mother plants in first year and during the first and second ratoon fruits are harvested from the suckers. Depending on the position of sucker with respect to the mother plant, the fruits in first and second ratoon may have inclination from vertical. This angle of inclination of fruit from vertical as shown in figure 3.1 was determined with the help of two steel rules. The measurements 'a' and 'b' for randomly selected fruits were measured and then the angle of inclination, ϕ was calculated using equation 1.

$$\tan(90-\phi)=\frac{a}{b} \qquad \ldots\ldots\ldots\ldots.. (1)$$

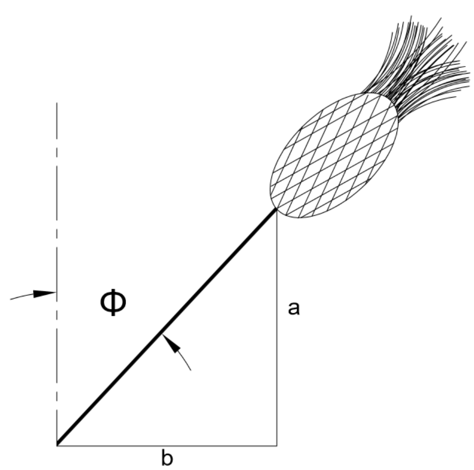


Figure 3.1 Angle of inclination of fruit from vertical

3.1.1.6 Number of Suckers

The growth of suckers plays a vital role in the design of harvesting machinery. Suckers are the major vegetative propagule in commercial pineapple cultivation. The number of suckers was counted on randomly selected plants.

3.1.1.7 Visible Length of Stem

The visible length of stem will help the operators in easy positioning of fruits in holders at the time of harvesting. The readings were taken on randomly selected plants in the field using a standard tape.

3.1.1.8 Foliar Coverage

The horizontal distance measured between the tips of most protruding leaves on either side of the plant was recorded as the foliar coverage. The readings were taken randomly with respect to period of ratoon using a standard tape.

3.1.2 Stem

The pineapple stem at the centre of plant bears the fruit. The diameter of stem was recorded with respect to period of ratoon. The measurements were taken with the help of vernier caliper having 0.01 mm least count.

3.1.3 Fruit

The parameters of fruit namely, fruit weight, length of fruit, diameter, and circumference were recorded. Weight of fruit from the mother plant, and from the suckers in the first and second ratoon was measured using a digital weighing balance. The length of fruit from top to bottom excluding the crown was measured using standard tape.

Diameter and circumference of fruit were noted at the top, middle and bottom side with respect to the period of ratoon. Diameter of fruit was measured using outside caliper and steel rule. Circumference was measured with a standard tape.

3.2 MOISTURE CONTENT

The average moisture content of the stem and leaves were determined on wet basis by oven dry method. The samples collected from the field are weighed using a digital weighing balance of ±0.01 g accuracy. The weighed samples were dried in oven for 24 hours at 103° C. The dried samples were taken out and weighed again (ASABE, 2006 cited by Hemmatian, 2012).

$$\text{Moisture content}\ (\%\ wb) = \frac{W_i - W_d}{W_i} \times 100 \qquad \ldots\ldots\ldots\ (2)$$

(Taghinezhad *et al*., 2013)

Where,

W_i: Initial weight of sample, g

W_d: Weight of dried sample, g

3.3 CUTTING ENERGY AND FORCE

3.3.1 Cutting Energy

The energy required for cutting the stem and leaves of pineapple were determined with the help of an impact test rig. The pendulum arm of the apparatus allows swinging freely in a vertical plane. By the principle of conservation of energy, as the pendulum releases from the initial position (upswing), its potential energy is converted to kinetic energy. There will be a continuous exchange of energy of the oscillating arm from its maximum potential energy at the upswing position to maximum kinetic energy at its lower point of oscillation. Hence, the specimen to be cut is placed at the point of maximum kinetic energy of the oscillating arm. When the pendulum hit the specimen, a part of is kinetic energy was utilised for cutting the material and with the remaining energy pendulum will continue its oscillation. The frictional losses of the swinging arm and the air resistance are small in magnitude and hence possibly neglected (Yiljep and Mohammed, 2005).

The pendulum arm was provided with cutting blade at its free end. At the time of experiment, the specimen either the stem or leaf of pineapple was hold vertically at the lower point of oscillation of the pendulum arm with the help of a vice. The pendulum arm was then released from an angular displacement of Θ_1. The blade cuts the specimen at the lower point of oscillation and move forward up to an angular displacement of Θ_2 (Dange *et al.*, 2011)

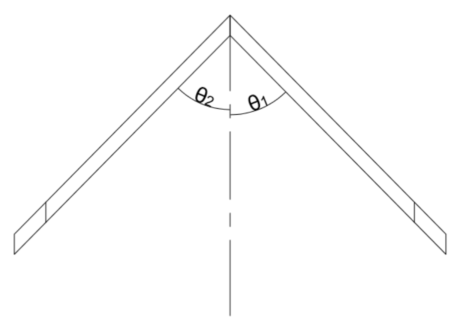


Figure 3.2 Pendulum arm assembly

The energy utilised for cutting a stem or leaf is calculated by the following equation:

$$E = Wg\,L\,(\cos \Theta_2 - \cos \Theta_1) \qquad \text{…...………….. (3)}$$

In which,

E : Cutting energy required for stem or leaf, Nm

W : Weight of oscillating pendulum, kg

Θ_1 : Maximum angle of deflection of the pendulum from vertical at initial position, Degree

Θ_2 : Maximum angle of deflection of the pendulum from vertical after cutting, Degree

L : Effective length of oscillating pendulum, m

The effective length of the pendulum arm was determined by oscillating the arm freely before the test specimen (stem or leaf) was clamped on the vice. The time taken (t) for 10 oscillations were noted. Three replications of the reading were taken to get the average time. Then the effective length of the pendulum arm was calculated with the help of equations 4 and 5.

$$T = \frac{\text{Time taken for 10 oscillations (t)}}{10} \qquad \text{…….. (4)}$$

$$T = 2\Pi\sqrt{\frac{l}{g}} \qquad \text{……… (5)}$$

Where,

l: effective length of pendulum arm, m

g: acceleration due to gravity, m/s^2

3.3.2 Cutting Force

The maximum cutting force requirement was calculated from the cutting energy as per the procedure explained under section 3.3.1. Figure 3.3 depicts the cutting force at different instances of blade movement through the stem. The cutting force increases from zero at initial of cutting and start i.e., the initial contact point to a maximum value, and becomes zero when cutting completes. The area under the graph gives the cutting energy requirement of one stem (Persson, 1987 cited by Baneh *et al.*, 2012).

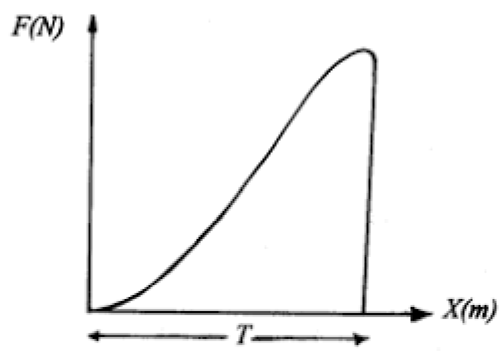


Figure 3.3 Cutting Force against blade movement (X) in stem diameter (T)

$$E = Fmax \times \frac{d}{2} \qquad \text{…………. (6)}$$

$$Fmax = \frac{2 \times E}{d} \qquad \text{…………. (7)}$$

For stem, length of travel of cutting blade is equivalent to the diameter of stem.

3.3.3 Construction Details of Test Rig

The test apparatus works on the principle of cutting energy was designed and fabricated in the research workshop of Kelappaji College of Agricultural Engineering and Technology, Tavanur. The fabricated impact test rig was similar to an izod impact apparatus for metal cutting. It consists of base frame, supporting frame, pendulum arm, pendulum shaft, cutting blade arrangement, dial gauge and a stalk holder.

3.3.3.1 Base Frame

A 550 x 550 mm square base frame was made of mild steel angles (ISA 3030). It was designed to provide enough structural stability and support. It acts as a mounting platform for supporting frame and stalk holder.

3.3.3.2 Supporting Frame

A supporting frame of 1 m height was provided. It was made of two hollow square pipes (20 x 20 mm) of mild steel. It was bolted to the base frame, which permits it to unbolt and carry separately to the field with ease. A rectangular MS plate (150 x 50 mm) was welded at the top of supporting frame, act as a platform for mounting the pendulum shaft.

3.3.3.3 Pendulum Shaft

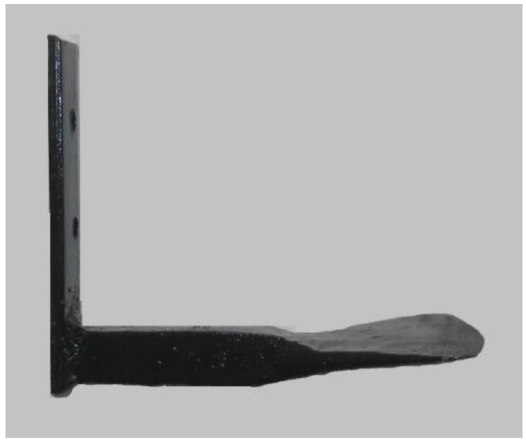
A horizontal shaft of 235 mm long was made of mild steel. It was supported only at one end, by welding it to the supporting frame. The free end of the shaft acts as a pivot point to the oscillating pendulum. The shaft was fabricated in stepped with two diameters, 20 mm and 15 mm. The length of shaft with 20 mm diameter was 200 mm measured from the supporting end. And the remaining 35 mm length of shaft has a diameter of 15 mm.

3.3.3.4 Pendulum Arm

The long pendulum arm was made of mild steel rod of 10 mm diameter and 800 mm length. It was suspended at the free end of horizontal shaft by means of a ball bearing (No. 6203) with inside diameter 17 mm. The pendulum arm was designed to swing freely in vertical plane with cutting blade attached to its lower end.

An axe like blade made of tempered mild steel was used to cut pineapple stem. The blade assembly was bolted to the pendulum arm. It has a cutting width of 6 cm. The pendulum arm along with the cutting blade weighs 2.35 kg.

A sharp and thin cutting material is required for the cutting of pineapple leaves, due to its high fiber content. Hence, a commercially available knife was purchased from the local market, and then it is modified to fix at the lower end of pendulum arm. The cutting arrangement for leaves consists of a rectangular blade of 65 x 95 x 1.5 mm dimensions sandwiched between two rectangular plates. The top and bottom plates were fabricated using mild steel with dimensions 35 x 95 x 3 mm and 114 x 95 x 3 mm respectively. The pendulum arm along with this cutting blade weighs 2.40 kg.



(a)

(b)

Plate 3.2 Blades used in test apparatus (a) for stem (b) for leaf

3.3.3.5 Dial Gauge

The angle of deflection of the oscillating pendulum arm was determined by using a dial gauge. It consists of an angular scale and a pointer mounted on the pendulum shaft. The angular scale of 250 mm diameter was graduated from 0º to 180º in one vertical half, and similarly in the other half. Pointer of length

130 mm was fabricated using mild steel. It was designed such that it moves together with the pendulum arm during its forward swing, after cutting the specimen. The pointer moves up to the maximum displacement point of the pendulum arm and remains at that position while the arm returns. The angular displacement of the pendulum arm can be read by the position of pointer before and after cutting the specimen.

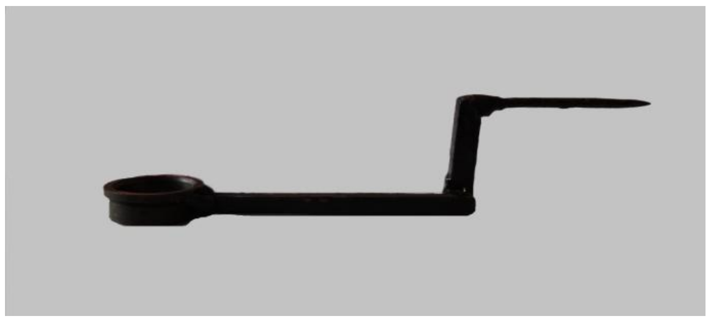


Plate 3.3 Dial gauge needle

3.3.3.6 Stalk Holder

A 50 mm drill press vice (code: 825S) was used to hold the specimens firmly during the experiments. The vice as bolted to the base frame at the point of maximum kinetic energy.

3.3.4 Measurement of Cutting Energy

The fabricated test rig was taken to the field for the determination of cutting energy. The cutting energy and cutting force of the stem were determined for plants of different age and for different moisture content. The cutting energy of leaves was determined with respect to age of leaves and moisture content. The leaves are grouped into three categories namely older leaves, younger leaves and most recent leaf to mature (D-leaves). A total of 15 replications of each experiment were conducted and the samples were collected for the moisture content determination.

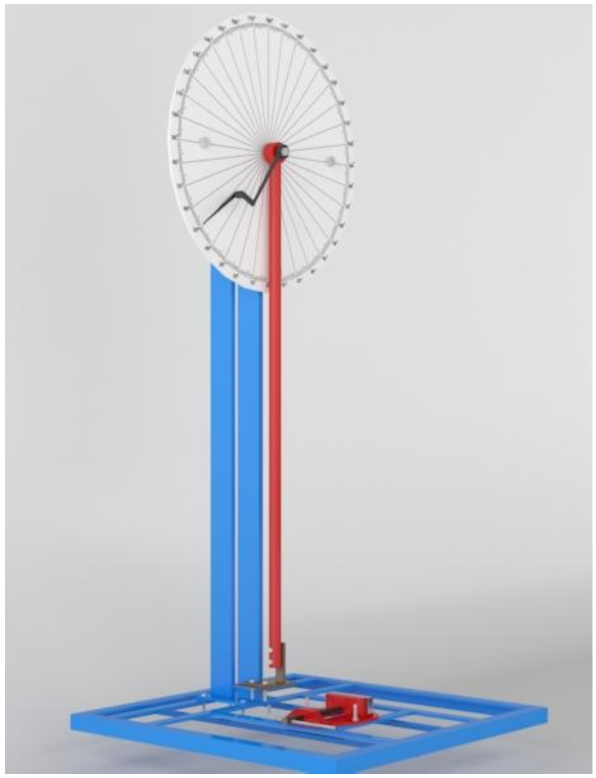


Figure 3.4 Impact test apparatus

Plate 3.5 Bearing- pendulum arm

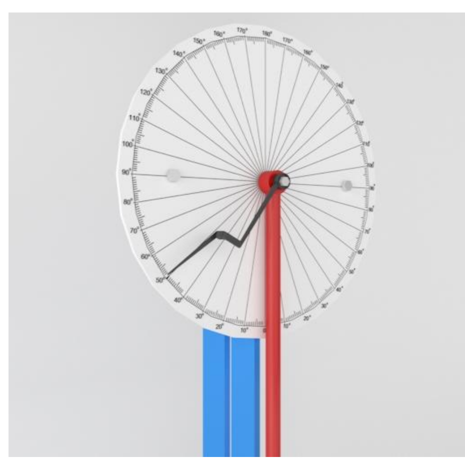


Figure 3.5 Dial gauge

3.4 DESIGN AND FABRICATION OF PINEAPPLE HARVESTER

The design procedure of a mechanical harvester of any crops includes the selection of a suitable power source, cutting mechanism, appropriate mechanism for detaching fruit from the stalk, holding and conveying the harvested fruit to the basket.

3.4.1 Prime Mover

The power source should select based on its availability in the market, cost of operation and maintenance, ability and suitability to perform the harvesting operation. By considering these, a backpack brush cutter was selected as the power source. The details of selected brush cutter was given in table 3.1.

Table 3.1 Details of Brush cutter

Make	STIHL
Engine	Single cylinder two-stroke engine
Displacement	30.5 cc
Engine Power	0.81 kW
Speed	6000 rpm
Weight	9.4 kg

3.4.2 Fruit Holders

Preliminary studies has indicated that research works were conducted for developing suitable attachments to brush cutters for harvesting paddy, sugar cane, etc. harvesting attachment suitable for paddy is available commercially.

Dixit *et al*., 2015 reported the development of a prototype for pineapple harvesting using brush cutter suitable for the hilly slope areas of northeastern India. It was found to work satisfactorily. Another study was undertaken to develop a pineapple harvesting attachment for brush cutter (Plate 3.7) at Kelappaji College of Agricultural Engineering and Technology, Tavanur in the year 2015-16. Based on the holders used in these studies, three different types of fruit holders were designed and fabricated suit to brush cutter.

The fruit holder was designed such that, it can hold a single fruit while harvesting. The fruit holder was mounted vertically above the cutting blade. The study consists of fabrication of three fruit holders. Field evaluation of the three fruit holders are conducted in comparison with the existing holder.

The existing holder named as holder-A, is fixed with respect to the cutting edge and supports the fruit throughout the harvesting operation. Holder-1 can move with respect to the cutting edge and supports the fruit throughout the harvesting operation. Holder-2 can grip the fruit but the distance and between the cutting edge and holder is fixed. Holder-3 can grip the fruit and can move with respect to the cutting edge.

A common base plate was fabricated for mounting the first and third design. A spring (10 mm diameter and 130 mm long) and cable arrangement was provided along with the base plate. This arrangement helps to vary the distance between the cutting edge and holder over a range of 25 mm by a back and forth motion. The height between the bottom of base plate and the blade was fixed at 260 mm.

3.4.2.1 Holder- A

The existing model for harvesting pineapple was given in plate 3.6. It consists of a 180 mm diameter round base plate made of GI sheet, a welded mesh cover and two crop guides. The holder-A was mounted vertically above the cutting blade of brush cutter.

3.4.2.2 Holder-1

This design consisted of a U-shaped holder made of mild steel sheet. The diameter of holder was fixed at 160 mm and the total height of the holder was 135 mm. It was bolted to the base plate. Both the holder and base plate supports the fruit while harvesting and transferring the harvested fruit. The 65 mm longer supporting surface of the holder provides a better lateral support for the fruits. Figure 3.6 shows the orthographic view of the holder-1.

3.4.2.3 Holder-2

The second design consisted of a finger like holder, to grip the fruit during harvesting and transferring. It was mounted on a 115 x 80 x 2 mm rectangular plate, which is bolted to the brush cutter. Each of the two fingers of the holder is provided with a rectangular piece of mild steel (65 x 25 x 2 mm), which can provide lateral support to the fruits. The gripping action of holder can be controlled by a spring and cable arrangement. The diameter of the holder can vary between maximum of 145 mm and minimum of 90 mm. The holder alone gives support to the harvested fruit. Figure 3.7 shows the orthographic view of the holder-2.

3.4.2.4 Holder-3

The third design consisted of a finger like holder, made of two square pipes (10 x 10 mm) of mild steel. The holder was bolted to the base plate. The holder can grip the fruit tightly while harvesting and transferring. The gripping action of holder can be controlled by a small tension spring and cable arrangement. The diameter of the holder can vary from 100 to 160 mm. Both the holder and base plate together aid in holding and conveying the harvested fruit. Figure 3.8 shows the orthographic view of the holder-3.

3.4.3 Cutting Blade

Brush cutters commonly use different types of cutting heads depending up on the type of material to be cut. This includes nylon rope, two edge blade, three edge blade, circular blade etc. Among these, circular blade is suitable for harvesting. Hence, three commercially available circular blades of 250, 175, and 150 mm diameter were selected for the study.

(a) **(b)** **(c)**

Plate 3.5 Cutting Blades (a) 250 mm diameter (b) 175 mm diameter (c) 150 mm diameter

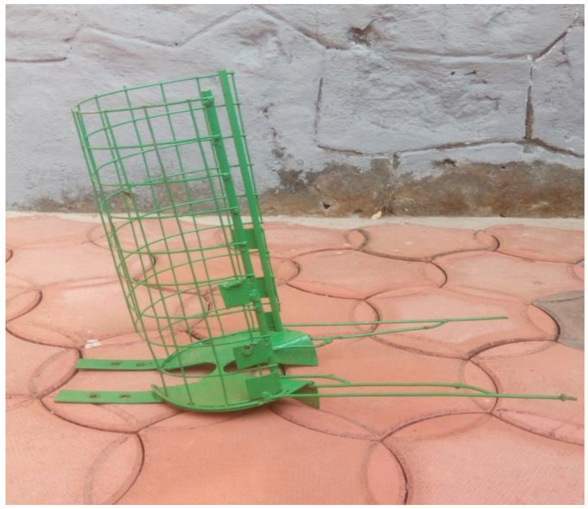


Plate 3.6 Fruit holder-A

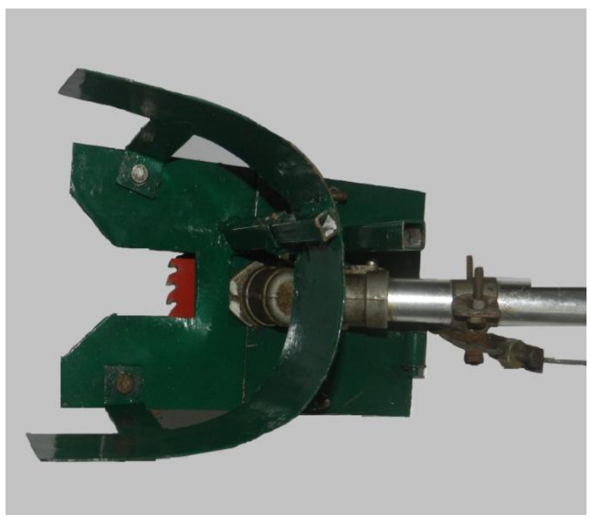


Plate 3.7 Fruit holder-1

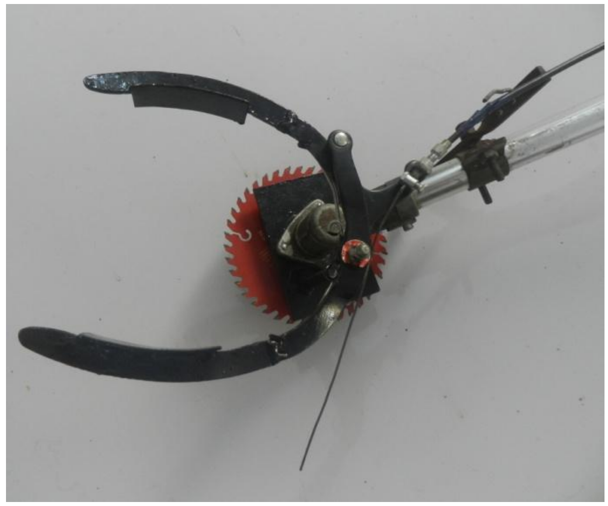


Plate 3.8 Fruit holder-2

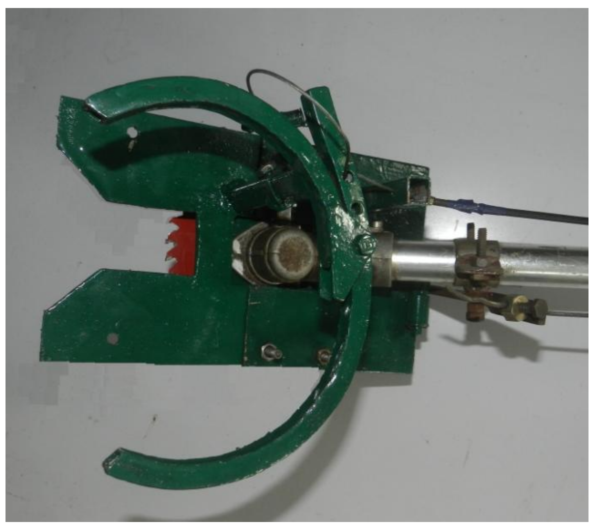


Plate 3.9 Fruit holder-3

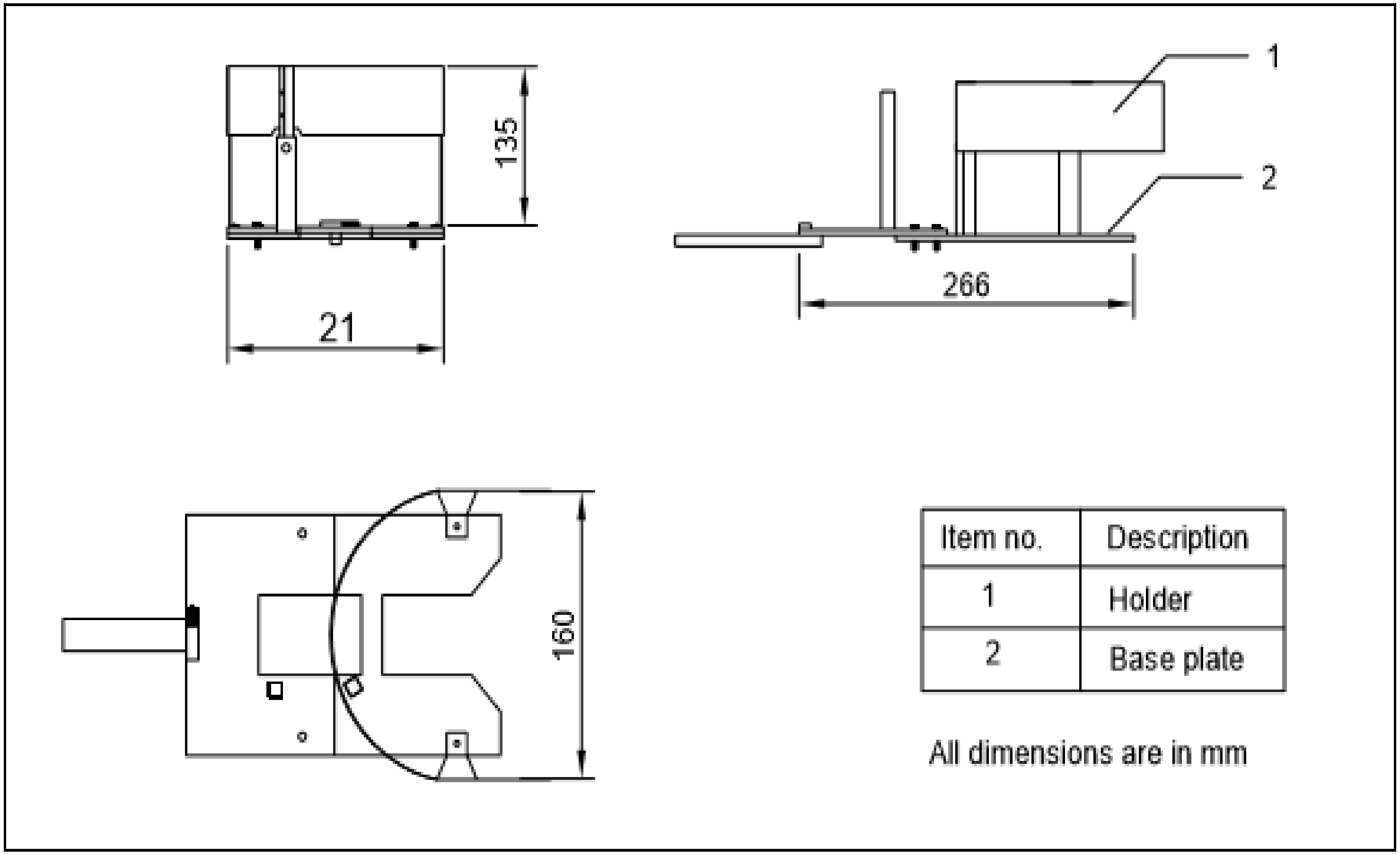


Figure. 3.6 Fruit holder-1

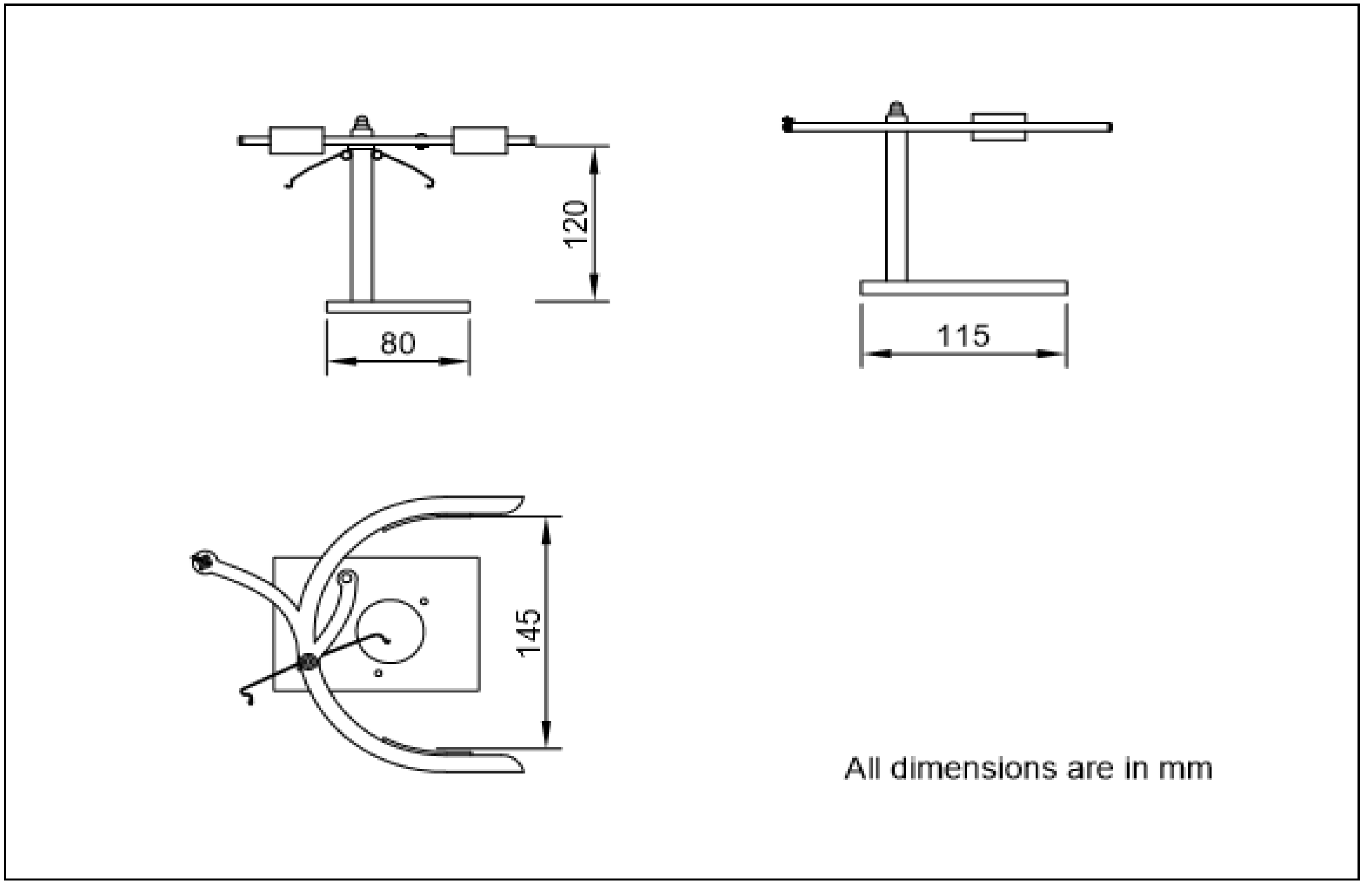


Figure. 3.7 Fruit holder-2

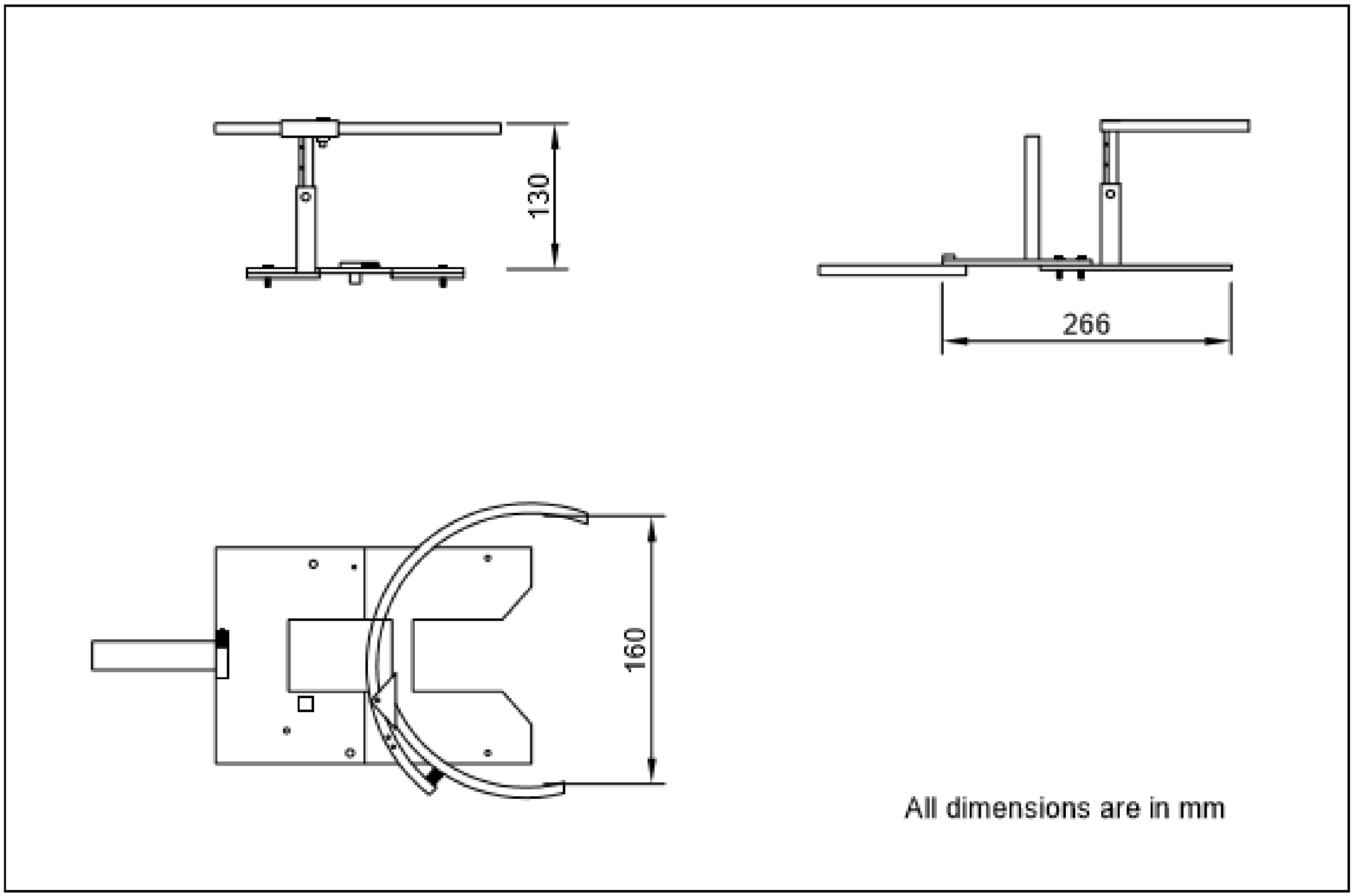


Figure. 3.8 Fruit holder-3

Plate 3.10 Brush cutter with fruit holder-1

Plate 3.11 Brush cutter with fruit holder-2

Plate 3.12 Brush cutter with fruit holder-3

3.5 FIELD EVALUATION

The fruit holders were operated in the field and were evaluated for its parameters including time of operation, fuel consumption, number of leaves cuts while harvesting, length of stem with the harvested fruit, holding and transferring of fruits, and operator's comfort.

3.5.1 Time of Operation

The total time required for harvesting 10 fruits by each holder-blade combination was determined. The total time accounts the harvesting time, time to drop the fruit safely in the basket, time taken by the operator to move from one plant to the other plant, and any other down time during the operation. The time was noted using a stopwatch.

3.5.2 Number of Leaves Cut Near Peduncle

The number of leaves cut while harvesting was counted for each of the operation. The increased number of damaged leaves increases the energy requirement of harvesting. As the next harvest is from suckers and as the major vegetative propagule, damages of suckers are not desirable.

3.5.3 Length of Peduncle Cut

The length of stem cut with the harvested fruit was measured using steel rule. If the length of cut was more then, it should reduce for ease in handling and transporting.

3.5.4 Fuel Consumption

The fuel consumed by the brush cutter for a continuous operation was determined. The fuel tank was filled before starting the operation. The quantity of fuel required to refill the tank after operating the brush cutter for 20 minutes were noted. The fuel consumption per unit-harvested area was estimated from the recorded data.

3.5.5 Holder Efficiency

Harvesting process of pineapple fruit using brush cutter includes positioning of fruit inside the holder, cutting the stem and safe transferring of fruit to ground. The harvesting operations using all the holders were same except the method of positioning the fruit. For the holder-A, as the operator moves towards the fruit, it will fall to the holder and is supported by the welded mesh and base plate. For holder one proper positioning of fruit can do by adjusting the base plate to either forward or backward direction. The fruit has support at the base and along its length. For holder two, the positioning of fruit can do by both adjusting the base plate and by gripping the fruit by the holder. The fruit has support at the base and along its length. For holder three the positioning of fruit can do by gripping the fruit with finger like holder. The fruit has support only along its length. As the fruit was held in the holder safely, the stem can cut by operating brush cutter blade. After detaching the fruit from the plant, it can safely drop to the side by lowering the whole unit.

The number of fruits properly harvested and transferred out of the total number of fruits harvested by each of the holders was counted during the field evaluation.

3.5.6 Operator's Comfort by Garret's Ranking Method

Garret's ranking method consists of a set of sequential procedures to select a suitable fruit holder from the group of the holders based on the ranks assigned by operators.

Three workers including two men and one woman were allowed to operate the harvesting unit with each of the holders for harvesting 10 fruits. Moreover, they are asked to assign ranks to each of the holder based on their comfort. The given rank of each fruit holders was then converted to percent values using the equation 8.

$$\text{Per cent position} = 100 \times \frac{\text{Rij - 0.5}}{\text{Nj}} \qquad \text{................ (8)}$$

Where,

R_{ij}: Rank given for the i^{th} factor/fruit holder by the j^{th} operator

N_j: Number of factors ranked by the j^{th} operator

The score corresponding to the percent position of each holder was then taken from the Garret's ranking table given by Garret and Woodworth, 1969. The mean scores are then arranged and ranked in descending order (Balaganesh *et al*., 2016).

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the relevant physical properties of pineapple plant and fruit and they are determined and summarised. The details of field experiments done to determine the cutting energy and cutting force requirement of pineapple stem and leaves were discussed in this chapter. This chapter also deals with the field evaluation of developed pineapple harvesting attachments to brush cutter.

4.1 PHYSICAL PROPERTIES

Physical properties of a mature pineapple plant, stem, and fruit were determined and discussed in the following sub-divisions.

4.1.1 Plant

Physical properties of pineapple plant such as plant height, number of leaves in mature plant, height of fruit from ground, angle of inclination of fruit, number of suckers, visible length of stem, and foliar coverage of a single plant were determined, using the procedure explained in the chapter 3. The details of these study are presented in the following sections.

43.1.1.1 Planting Geometry

The general planting practice adopted for pineapple in Kerala is in paired rows. The suckers are planted at 37.5 cm apart keeping 45 cm spacing between the paired rows. To get maximum yield without losing the fruit quality, a plant density of 8500 plants per acre is maintained by the farmers.

4.1.1.2 Height of Plant

Details of height of plant were given in table A1 in Appendix. The average height of a pineapple plant was obtained as 94 cm with a standard deviation of 20.6 cm. The minimum and maximum value of plant height was recorded as 70 and 130 cm respectively (table 4.1).

4.1.1.3 Number of Leaves in a Mature Plant

The number of leaves in a mature plant was given in table A1. The value shows a varied pattern ranging from 25 to 76. The average value obtained as 47 with a standard deviation of 13.20 (table 4.1).

4.1.1.4 Height of Fruit from Ground

The details of fruit height measured from the ground level were given in the table A1. The results found that the height of fruit was varying from 21 cm to 50 cm, with an average value of 33.2 cm and standard deviation 8.6 cm.

4.1.1.5 Angle of Inclination of Fruit

The angle of inclination of fruit measured from the vertical was given in table A1. The value shows a varied pattern ranging from 10.5º to 70.3º. The varied angle of inclination may depend on whether the fruit forms on mother plant or sucker, strength of stem, topography, etc. The average value obtained as 38.2º with a standard deviation of 19.7º.

Table 4.1 Morphological Details of a Mature Plant

	Minimum	Maximum	Mean	Std. Deviation
Height of plant, cm	70.0	130.0	94.6	20.6
No. of leaves in mature plant	25	76	45	13.2
Height of fruit from ground, cm	21.0	50.0	33.2	8.6
Angle of inclination of fruit, degrees	10.5	70.3	38.2	19.7

4.1.1.6 Number of Suckers

In commercial cultivation of pineapple, the suckers has market value as it is the major vegetative propagule. Suckers are born on the mother plant after each harvesting of fruit. It was observed that the number of suckers in a plant was varying greatly from 0 to 6.

4.1.1.6 Visible Length of Stem

The visible length of stem was given in the table A2. The result showed that the period of ratoon is significant in terms of visible length of stem. The length of stem during the first harvest is more visible than in other. As the time passes, the visibility of stem reduces due to the growth of suckers. In most of plants in second harvest, stem are rarely visible. The average length of visible stem during the first harvest was observed as 10.38 cm with standard deviation of 2.27 cm. The average length of visible stem in first ratoon was observed as

6.32 cm with standard deviation of 4.08 cm and in second ratoon 1.92 cm with standard deviation of 0.95 cm.

Table 4.2 Details of visible length of pineapple stem with respect to period of ratoon

Visible Length of Stem, cm				
Period of ratoon	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
First harvest	6.50	15.00	10.38	2.27
First ratoon	1.00	14.00	6.32	4.08
Second ratoon	1.00	3.50	1.92	0.95

4.1.1.7 Foliar Coverage

The foliar coverage of the pineapple plants in each ratoon were measured and described in the table A3 and table 4.3. The average foliar coverage of mother plants were found as 78.3 cm with a standard deviation of 28.50 cm. The average foliar coverage in first ratoon were found as 97.5 cm with a standard deviation of 23.01 cm and in second ratoon were found as 130.9 cm with a standard deviation of 18.80 cm. It can conclude that the foliar coverage of single plant were increases as time passes. This was due to the growth of suckers in the plant with time, which makes the field denser and covers inter space between the paired rows.

Table 4.3 Details foliar coverage of pineapple plant with respect to period of ratoon

Foliar Coverage, cm				
Period of ratoon	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
First harvest	48.00	125.00	78.25	28.50
First ratoon	60.20	130.50	97.50	23.01
Second ratoon	90.50	150.00	130.97	18.80

4.1.2 Stem

The diameter of pineapple stem in each period of ratoon was given in table B1. The average value of stem diameter from mother plant was recorded as 37.27 mm with a standard deviation of 4.38 mm. The average value of stem diameter in first ratoon was recorded as 23.92 mm with a standard deviation of 2.28 mm, and in second ratoon 18.87 mm with a standard deviation of 3.61 mm. The total average of stem diameter was 26.69 mm. Statistical analysis showed that the period of ratoon significantly influence the diameter of pineapple stem since $P < 0.05$ at 5 per cent significance level. It was found that the diameter of stem in mother plant was higher than in the first and second ratoon. The maximum stem diameter recorded was 43.5 mm, from the mother plant and the minimum diameter recorded was 14.8 mm in second ratoon plant.

Table 4.4 Details of pineapple stem diameter with respect to period of ratoon

Stem Diameter, mm				
Period of ratoon	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
First harvest	29.00	43.50	37.27	4.38
First ratoon	19.00	27.30	23.92	2.28
Second ratoon	14.80	26.00	18.67	3.61

Table 4.5 Statistical results of pineapple stem diameter with period of ratoon

Stem_Diameter	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2711.148	2	1355.574	108.469*	.000
Within Groups	524.891	42	12.497		
Total	3236.039	44			

*Significant at 5% level

4.1.3 Fruit

The fruit dimensions viz., fruit length, diameter, girth and weight with respect to period of ratoon were given in table C1. The statistical analysis given in table 4.6 showed that the period of ratoon is significant with the length of fruit ($P < 0.05$ at 5 per cent significant level). It was found that the fruit length was decreasing with period of ratoon. The maximum fruit length of 36 cm was found in fruits from the mother plant and the minimum fruit length of 13 cm was found in fruits from second ratoon plants. The average fruit length during the first harvest was found as 32.7 cm with a standard deviation of 2.58 cm. The average fruit length in first ratoon was found as 17.9 cm with a standard deviation of 2.52 cm and in second ratoon, it was observed as 14.9 cm with a standard deviation of 2.12 cm.

Statistical analysis showed that period of ratoon is significant with the fruit diameter ($P < 0.05$ at 5 per cent significant level). There was no significant difference between the values of diameter during the first harvest and first ratoon, whereas in second ratoon the diameter of fruit was found decreased. The maximum fruit diameter of 12.30 cm was observed during the first harvest and minimum diameter of 8.41 cm was observed in second ratoon.

Statistical analysis showed that period of ratoon is significant with the weight of fruit ($P < 0.05$ at 5 per cent significant level). The weight of fruit was found decreasing with the period of ratoon. No significance difference was observed between weight of fruit in first harvest and first ratoon. The maximum weight of fruit, 1.8 kg was obtained during the first harvest and minimum weight, 0.50 kg obtained in second ratoon. The average fruit weight during the first harvest was obtained as 1.42 kg with a standard deviation of 0.21 kg. The average fruit weight in first ratoon was obtained as 1.18 kg with a standard deviation of 0.26 kg and in second ratoon, it was obtained as 0.90 kg with a standard deviation of 0.23 kg.

In commercial market, fruits are sorted into three different classes on the basis of fruit weight. The fruit weighing less than 0.8 kg is grouped as class C; fruits weighing 0.8-1.2 kg grouped as class B; and the fruits weighing more than 1-2 kg grouped as class A. The details are given in table C4, table C5, and table C6.

Table 4.6 Statistical results of pineapple fruit length, diameter and weight with period of ratoon

		Sum of Squares	df	Mean Square	F	Sig.
Fruit Length	Between Groups	1805.417	2	902.708	154.211*	.000
	Within Groups	158.050	27	5.854		
	Total	1963.467	29			
Fruit Diameter	Between Groups	10.569	2	5.285	17.617*	.000
	Within Groups	8.100	27	0.300		
	Total	18.669	29			
Fruit Weight	Between Groups	1.366	2	0.683	12.379*	.000
	Within Groups	1.490	27	0.55		
	Total	2.856	29			

* Significant at 5% level

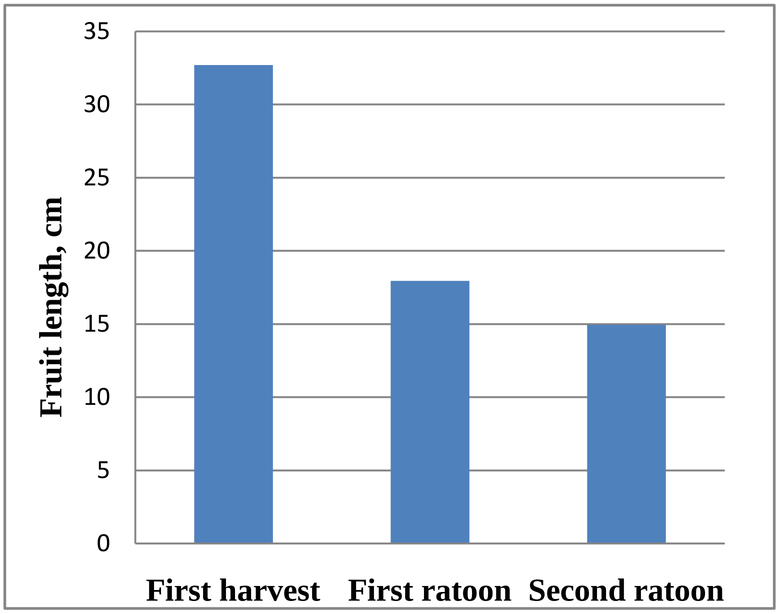


Figure 4.1 Pineapple fruit length against period of ratoon

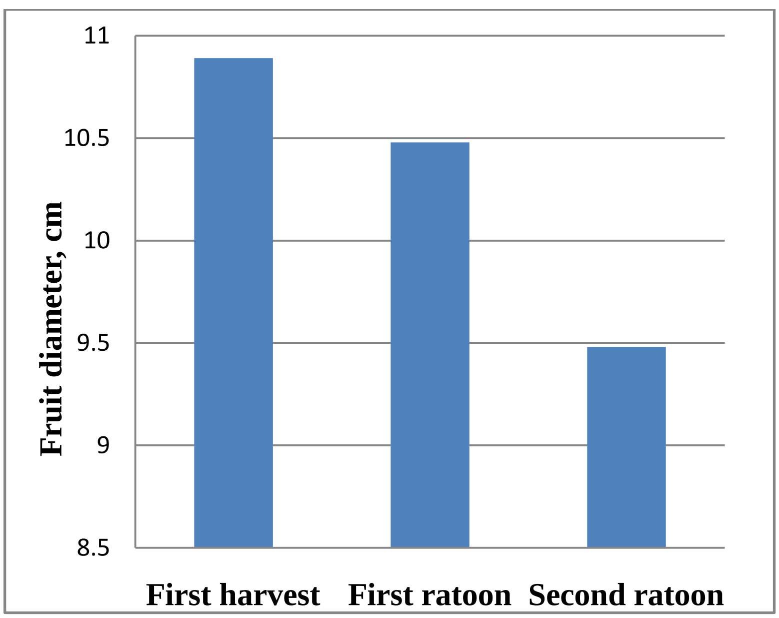


Figure 4.2 Pineapple fruit diameter against period of ratoon

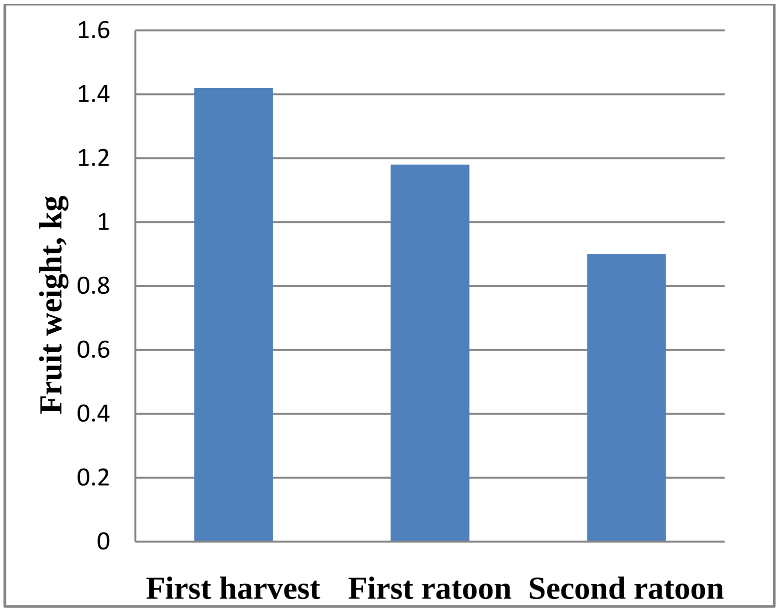


Figure 4.3 Pineapple fruit weight against period of ratoon

4.2 MOISTURE CONTENT

4.2.1 Moisture Content of Pineapple Stem

The details of moisture content of pineapple stem was given in Appendix D. The average moisture content obtained during the first harvest, first and second ratoon were 91.17%, 90.91%, 90.18% respectively. The total average moisture content obtained as 90.76% with a standard deviation of 1.37%. The maximum moisture content 93.24% was observed in first ratoon plants and minimum moisture content 88.17% was observed in second ratoon plants. Analysis of variance of moisture content of pineapple stem was done to study the effect of period of ratoon. It was concluded that the period of ratoon was insignificant in terms of moisture content of pineapple stem, since $p > 0.05$ at 5 per cent significance level.

Table 4.7 Statistical analysis of stem moisture content with period of ratoon

Moisture Content	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.225	2	2.612	1.433	0.256
Within Groups	49.219	27	1.823		
Total	54.44	29			
CV = 1.38					

4.2.2 Moisture Content of Pineapple Leaves

The details of moisture content of pineapple leaves are given in table D4, table D5, and table D6. The average moisture content obtained in the old leaves, D-leaves, and young leaves were 85.65%, 86.85%, 87.22% respectively. The total average moisture content obtained as 86.57% with a standard deviation of 1.59%. The maximum moisture content 88.90% was observed in younger leaves and minimum moisture content 82.30% was observed in older leaves. Analysis of variance of moisture content of pineapple leaves was done to study the effect age of leaves. It was concluded that the age of leaves was insignificant in terms of moisture content of pineapple leaves, since $p > 0.05$ at 5 per cent significance level.

Table 4.8 Statistical analysis of moisture content of leaves with age of leaves

Moisture Content	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	13.446	2	6.723	3.049	.064
Within Groups	59.536	27	2.205		
Total	72.983	29			
CV = 1.35					

4.3 CUTTING ENERGY AND FORCE REQUIREMENT OF PINEAPPLE STEM

The energy required for cutting pineapple stem at nodes and internodes were determined experimentally. The experimental results of cutting energy and cutting force with respect to period of ratoon were given in Appendix E. The cutting of stem was achieved by the combined effect of shear failure accompanied by the deformation due to bending and compression (Kepner *et al.,* 1987). As the pineapple stem was strong in bending and provide enough inertia of being cut to support the opposing force required in shearing, the effect of shear failure was prominent in cutting action than bending. The cutting energy of pineapple stem and the effect of moisture content on cutting energy and force was discussed in the following sub-divisions.

4.3.1 Cutting Energy of Stem

Figure 4.4 shows the cutting energy requirement of pineapple stem in each of period of ratoon at node and inter node position of stem. Analysis of variance of cutting energy with period of ratoon was given in table 4.9 and 4.10. Statistical analysis shows that of period of ratoon was significant in terms of energy requirement, since $P < 0.05$ at 5 per cent significant level. The energy required for cutting pineapple stem both at node and inter node position was more in mother plants. This is because of the increased diameter of stem in mother plants as discussed in section 4.1.2.

The cutting energy requirement was observed more at node position compared to inter node position. There was no significant difference between the cutting energy requirement in first and second ratoon plants. The maximum cutting energy obtained at node and inter node position was 18.10 J and 17.68 J respectively and the minimum energy at node and inter node position was 2.90 J and 2.83 J respectively. The details of cutting energy at node and inter node position was given in table E7 and table E8.

Table 4.9 Cutting energy of stem at node with period of ratoon

Cutting_Energy	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	535.226	2	267.613	70.867*	.000
Within Groups	101.959	27	3.776		
Total	637.185	29			

* Significant at 5% level

Table 4.10 Cutting energy of stem at inter node with period of ratoon

Cutting_Energy	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	391.696	2	195.848	44.876*	.000
Within Groups	117.833	27	4.364		
Total	509.530	29			

* Significant at 5% level

4.3.2 Effect of Moisture Content on Cutting Energy of Stem

Figure 4.5 shows the effect of moisture content on cutting energy requirement of pineapple stem. It was observed that the cutting energy was linearly varying with moisture content. The cutting energy was increases as the moisture content increases from 89 to 91%. Thereafter, the increase in moisture content decreases energy requirement of pineapple stem. This may due to the high tensile strength of pineapple stem fibre than leaf fibre (Yusof *et al.*, 2016). And increase in tensile strength due to the improvement of adhesion at amorphous components interface with moisture absorption upto a certain level. Further uptake of moisture could induce plasticising the amorphous matrix (Placet *et al.*, 2012). The maximum cutting energy of 1.67 J was obtained at 91% moisture level.

The average cutting energy at 89% moisture content was 7.99 J with a standard deviation of 1.64 J. The average cutting energy at 90% moisture content was 11.61 J with a standard deviation of 3.18 J. The average cutting energy at 91% moisture content was 13.49 J with a standard deviation of 2.74 J and at 92% moisture content was 10.87 J with a standard deviation of 2.96 J.

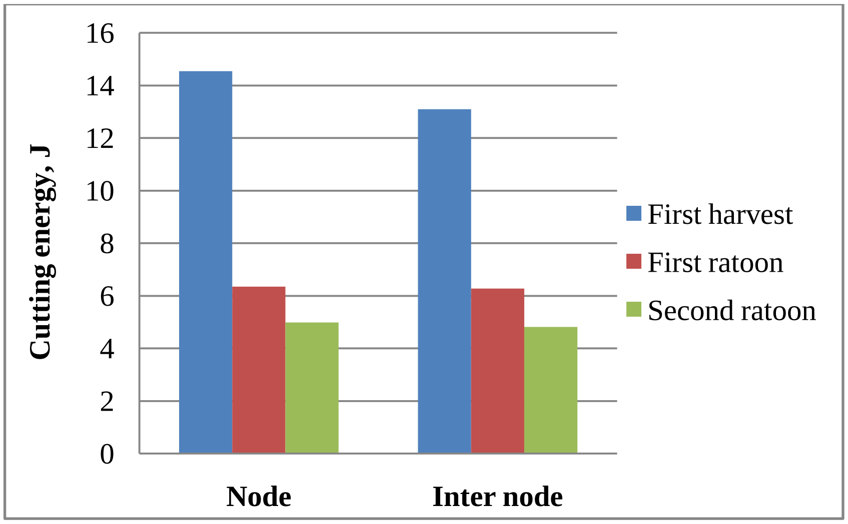


Figure 4.4 Cutting energy of pineapple stem against period of ratoon

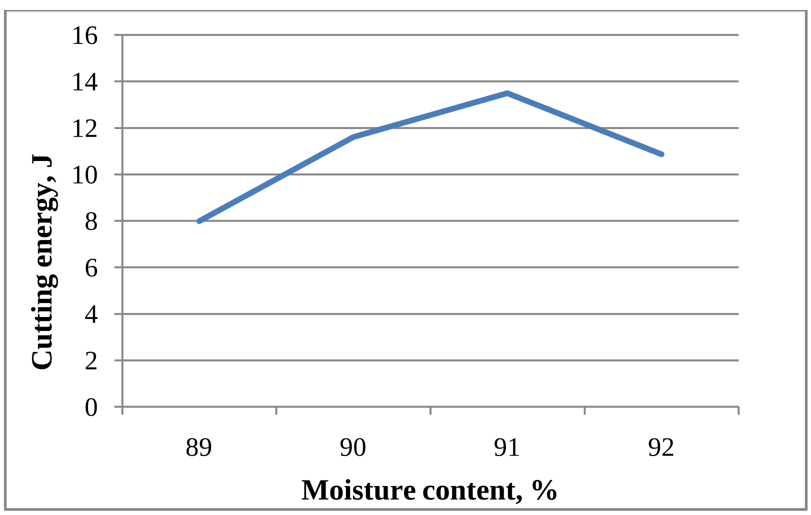


Figure 4.5 Cutting energy of pineapple stem against moisture content

4.3.3 Cutting Force of Stem

Figure 4.6 shows the cutting force of pineapple stem in each of period of ratoon at node and inter node position of stem. The statistical analysis concludes that the period of ratoon is significant for cutting force. The cutting force requirement of pineapple stem both at node and inter node position was found decreasing with the period of ratoon. There was no significant difference observed between the cutting force requirement of stem in first and second ratoon plants. This was due to the reduced stem diameter as time passes.

The force requirement is more at node position of stem compared to the inter node position. The total average force at inter node position was 573.71 N with a standard deviation of 129.81 N and the total average force at node position was 606.97 N with a standard deviation of 145.52 N. The maximum and minimum cutting force obtained in node was 842.7 and 311.7 N respectively. The same at inter node was 822.5 and 304 N respectively. The details of cutting force at node and inter node position was given in table E9 and table E10.

Table 4.11 Statistical analysis of cutting force at node with period of ratoon

Cutting_Force	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	363633.314	2	181816.657	19.595*	.000
Within Groups	250523.620	27	9278.653		
Total	614156.934	29			

* Significant at 5% level

Table 4.12 Statistical analysis of cutting force at inter node with period of ratoon

Cutting_Force	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	189830.982	2	94915.491	8.574*	.001
Within Groups	298893.273	27	11070.121		
Total	488724.255	29			

* Significant at 5% level

4.3.4 Effect of Moisture Content on Cutting Force

Figure 4.7 shows the effect of moisture content on cutting force requirement of pineapple stem. It was observed that the cutting force of varying linearly with moisture content. The cutting force was increases as the moisture content increases from 89 to 91%. Thereafter, an increase in moisture content leads to the decrease in cutting force requirement of pineapple stem. The reason may the same as discussed under 4.3.2. The maximum cutting force of 793.34 N was obtained at 91% moisture level.

The average cutting force at 89% moisture content was 659.06 N with a standard deviation of 87.96 N. The average cutting force at 90% moisture content was 662.91 N with a standard deviation of 102.90 N and at 91% moisture content was 736.51 N with a standard deviation of 66.71 N. The average cutting force at 92% moisture content was 677.30 N with a standard deviation of 94.04 N.

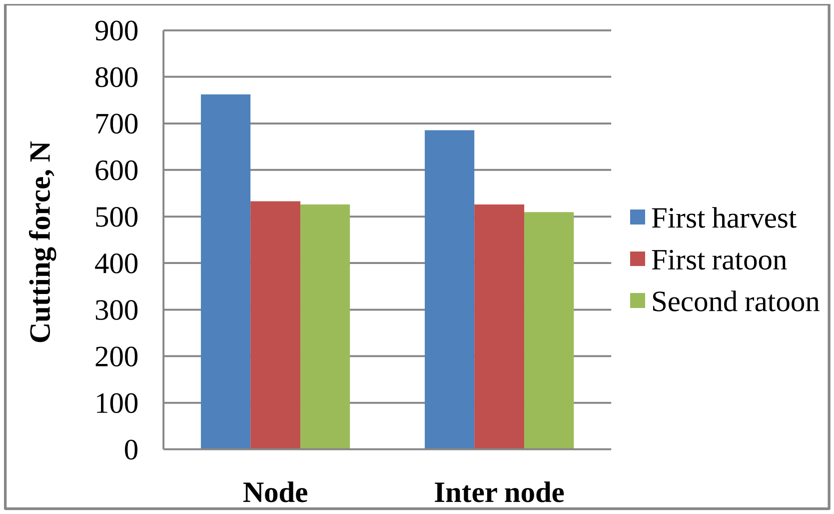


Figure 4.6 Cutting force of pineapple stem against period of ratoon

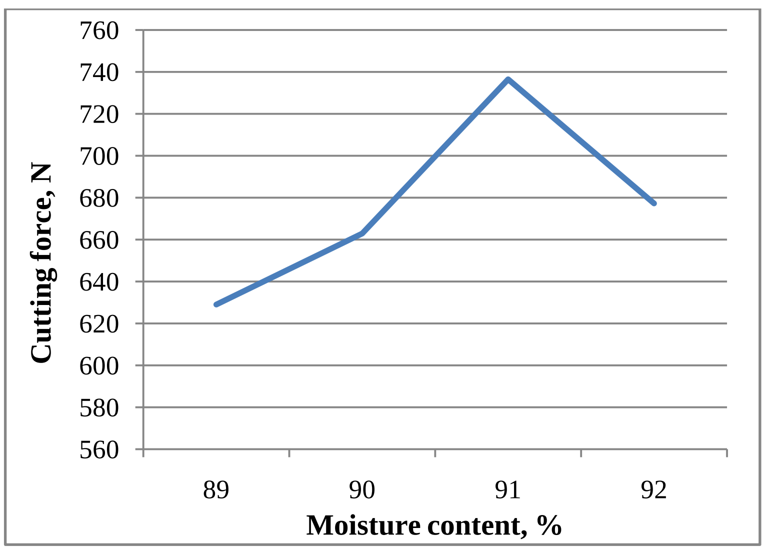


Figure 4.7 Cutting force of pineapple stem against moisture content

4.4 CUTTING ENERGY REQUIREMENT OF PINEAPPLE LEAVES

The energy required for cutting pineapple leaves were determined experimentally. The experimental results of cutting energy and cutting force requirement based on the age of leaves were given in Appendix F. In case of pineapple leaves, the cutting action was achieved by the effect of shear failure and compression due to bending. The pineapple leaf was not able to provide enough resisting force for shearing. Hence, the effect of deformation in bending was prominent in case of pineapple leaf cutting. The effect of age of leaves and moisture content of leaves on cutting energy requirement was discussed in following sub-divisions.

4.4.1 Effect of Age of Leaves on Cutting Energy of Pineapple Leaves

Figure 4.8 shows the effect of age of pineapple leaves on cutting energy requirement. The analysis of variance of cutting energy requirement with leaf age was given in table 4.13 and it shows that the age of leaves was significant in terms of cutting energy requirement of leaves as the $p < 0.05$ at 5 per cent significance level. It was observed that as the leaf age increases cutting energy also increases. The older leaves require higher cutting energy. No significant difference was observed in the cutting energy requirement of younger and D-leaves. The maximum and minimum cutting energy for leaves observed are 9.6 and 1.2 J respectively. The average energy requirement for old leaves was observed as 6.59 J with a standard deviation of 2.35 J. The average energy requirement for D-leaves was observed as 5.77 J with a standard deviation of 4.85 J and for young leaves, it was observed as 2.92 J with a standard deviation of 2.45 J.

Table 4.13 Statistical analysis of cutting energy with age of leaves

Cutting_Energy	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	74.225	2	37.113	10..001*	.001
Within Groups	100.190	27	3.711		
Total	174.415	29			

* Significant at 5% level

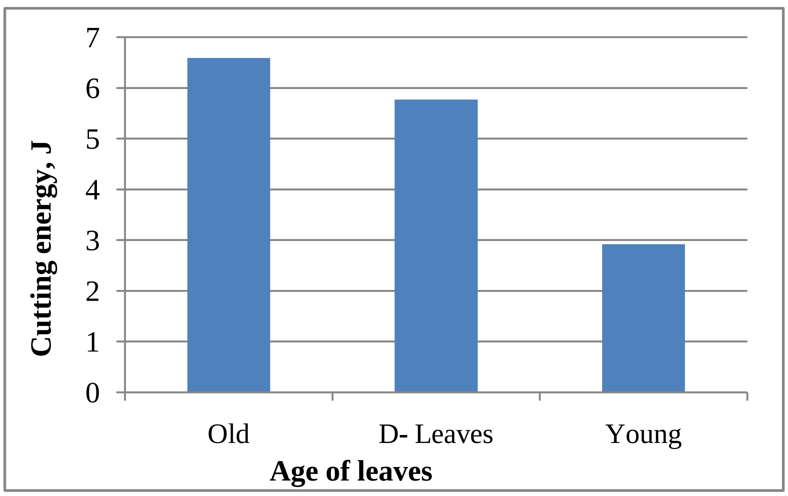


Figure 4.8 Cutting energy of pineapple leaves against age of leaves

4.4.2 Effect of Moisture Content on Cutting Energy of Pineapple Leaves

Figure 4.9 shows the effect of moisture content on cutting energy of pineapple leaves. It was observed that the cutting energy was decreasing, as the moisture content was increase from 85 to 86%. Thereafter, increase in moisture content leads to the increase in cutting energy requirement of pineapple leaves. This may due to that the pineapple leaf contains more fibre content than stem

(Yusof *et al.*, 2016) and water absorption showed increase with increase in fibre content and with increase in the number of days in water (Danladi and Shu'aib, 2014). The minimum average cutting energy of 4.24 J with a standard deviation 0.90 J was observed at 86% of moisture level.

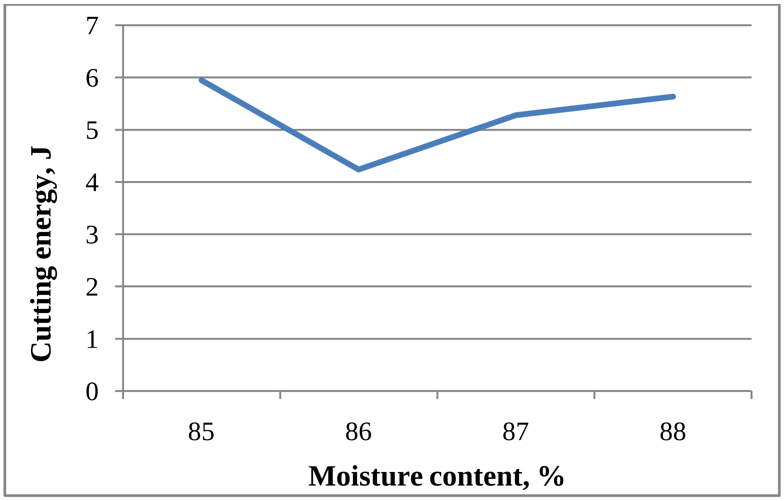


Figure 4.9 Cutting energy of pineapple leaves against moisture content

4.5 FIELD EVALUATION

The fruit holders were evaluated for its field performance. A trial test was conducted at the Pineapple Research Station, Thrissur and the field evaluation was conducted at pineapple field Chelakkara, Thrissur.

Trial evaluation of the fruit holders was conducted with three different cutting blades. The diameters of selected cutting blades are 150, 175, and 250 mm. It was observed that the harvesting of pineapple fruit with 150 and 175 mm diameter blades was satisfactory. The large diameter of 250 mm blade hindered the forward movement of holder, therefore it was found less effective than other two blades. Based on the trial, the blades with 150 and 175 mm were considered for the field evaluation of fruit holders. The observations made during the field evaluation of the holders including the time of operation, number of leaves cut near the peduncle, length of stem cut were discussed in the following sub-divisions.

Plate 4.1 Pineapple harvesting with holder-1

Plate 4.2 Pineapple harvesting with holder-2

Plate 4.3 Pineapple harvesting with holder-3

Plate 4.4 Pineapple harvesting with holder-A

4.5.1 Time of Operation

Statistical analysis of time of operation with fruit holder-blade combination was given in table 4.14. It was observed that time of operation was significant for fruit holder-blade combination, since $p < 0.05$ at 5 per cent significant level. Figure 4.10 shows the average time taken to harvest 10 fruits in a continuous pattern for each fruit holder-blade combination. It was observed that the combination of holder 1 and 150 mm diameter blade requires minimum time of operation, 5.01 minutes. The holder 2 and 175 mm diameter blade takes maximum time for harvesting, 13.43 minutes. Details of time of operation were given in table G1.

Table 4.14 Statistical analysis of time of operation with fruit holder- blade combination

Fruit holders	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	248.824	7	35.546	42.592*	.000
Within Groups	13.353	16	.835		
Total	262.177	23			

* = Significant at 5% level

4.5.2 Number of Leaves Cut Near Peduncle

Statistical analysis of number of leaves cut near the peduncle with fruit holder-blade combination was given in table 4.15. It was observed that number of leaves cut was significant for fruit holder-blade combination, since $p < 0.05$ at 5 per cent significant level. Figure 4.11 shows the average number of leaves cut for each fruit holder-blade combination. The minimum number of leaves cuts, 5 nos. was recorded for the combination of holder 1 and 150 mm diameter blade and the maximum damage of leaves, 12 nos. occurred for the combination of holder 2 and 175 mm diameter blade. The results showed that there was no significant difference between the combination A, B, C, D, G and H; and combination E and F. Details of number of leaves cut were given in table G2.

Table 4.15 Statistical analysis of number of leaves cut near peduncle with fruit holder- blade combination

Fruit holders	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	360.487	7	51.498	7.179*	.000
Within Groups	516.500	72	7.174		
Total	876.988	79			

* Significant at 5% level

(a)

(b)

(c)

Plate 4.5 Number of leaves cut while harvesting

4.5.3 Length of Peduncle Cut

Statistical analysis of length of peduncle cut with fruit holder-blade combination was given in table 4.16. It was observed that length of peduncle cut was significant for fruit holder-blade combination, since $p < 0.05$ at 5 per cent significant level. Figure 14.12 shows the average length of peduncle cut for each fruit holder-blade. The minimum length of peduncle cut, 71 mm was recorded for the combination of holder 3 and 150 mm diameter blade and the maximum length of cut, 123 mm occurred for the combination of holder A and 175 mm diameter blade. The results showed that there was no significant difference between the combination A, B and C and combination D, E, F, G, and H. The details of length of stem cut was given in table G3.

Table 4.16 Statistical analysis of length of peduncle cut with fruit holder-blade combination

Fruit holders	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	115.096	5	23.019	6.557*	.000
Within Groups	189.568	54	3.511		
Total	304.664	59			

* Significant at 5% level

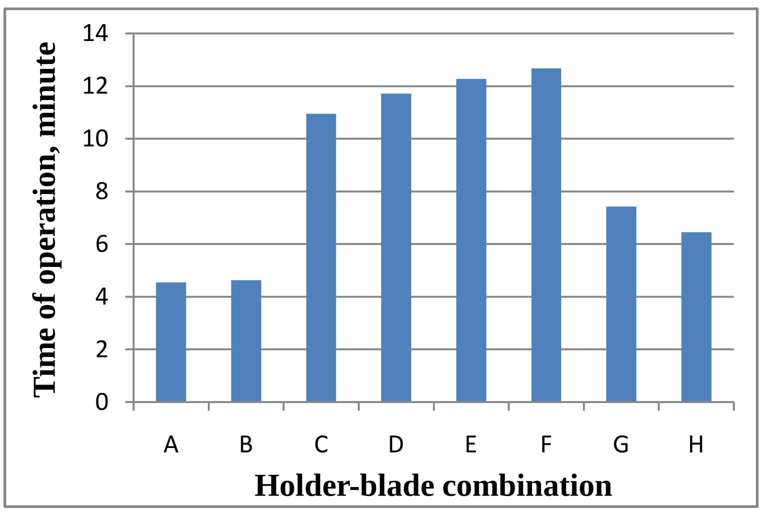


Figure 4.10 Time of operation against holder-blade combination

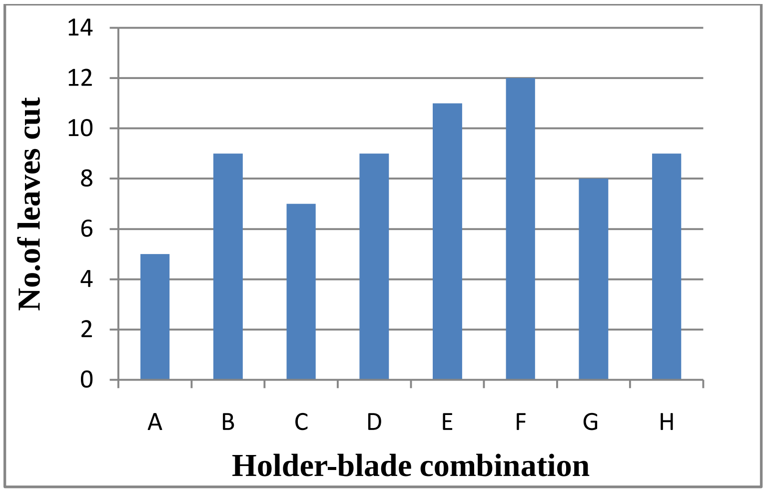


Figure 4.11 No. of leaves cut against holder-blade combination

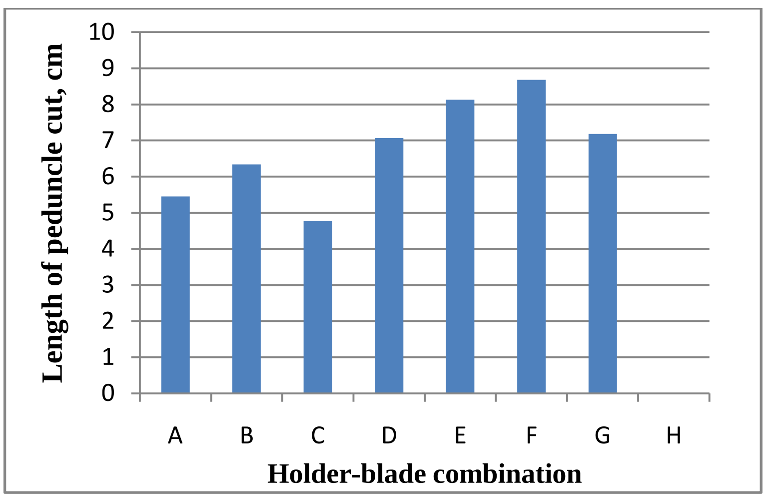


Figure 4.12 Length of peduncle cut against holder-blade combination

4.5.4 Fuel Consumption

Brush cutter was operated for cutting the pineapple leaves and stems in the field. The average fuel consumption for operating the brush cutter was observed as 560 $ml.h^{-1}$.

4.5.5 Holder Efficiency

The fruit holders were designed for holding fruit while harvesting and transferring to the ground or basket after harvesting. The positioning and holding of fruits in the holder will depend on the position of fruits, weight of fruits and dense nature of plant. It was observed that the fruits formed on suckers near to the ground were difficult to grip. The fruits with increased weight also were difficult to grip and support. The dense nature of plant also creates problems in positioning the fruits within the holder. The base plate and the longer U-shape of holder-1 help it to hold and support the fruits while harvesting. Hence, it can provide better support for the fruits compared to the other holders. It was found that during the field evaluation of holder-1, it properly holds and safely transferred an average of eight fruits out of 10 fruits harvested.

For holder-2, the fruits only have lateral support by the gripping fingers and it was not supported at the bottom side. Harvesting of inclined fruits can done with holder-2, but found less effective than holder-3, because of the absence of base support. It was found that holder-2 holds and safely transfers six fruits out of 10 fruits harvested. For the holder-3, the base plate provides support for the fruits at its bottom side and the lateral support by the gripping. The harvesting of pineapple fruits with higher angle of inclination can done properly with the holder-3 compared to any other holder. It was found that the holder-3, properly holds and safely transfers seven fruits out of 10 continuously harvested fruits.

The existing fruit holder i.e., holder-A was found working effectively in the field. The crop guides provided in the holder-A hindered the forward movement of holder, hence difficulty in proper positioning of the fruits. The long lateral support of the holder and base plate helps in proper holding and transferring of fruits. It was found that the holder-A holds and safely transfers seven fruits out of 10 fruits harvested.

4.5.6 Operator's Comfort by Garret's Ranking Method

The calculation procedure of Garret's ranking method was given in Appendix H. The result shows that the holder-1 i.e., fixed holder with a movable base plate, is more comfortable in handling. The holder-2 i.e., model without movable base plate and with grip got 4th rank, holder-3 i.e., model with movable base plate and with grip got 2nd rank, and the holder-A i.e., existing holder with fixed base plate got 3rd rank. Hence, we can conclude that the fixed holder with movable base plate was more comfortable in handling and operating.

(a) (b) (c)

Plate 4.6 Field evaluation of fruit holders

4.5.6 Performance of Fruit Holders

Field evaluation of the holders were conducted and it was observed that movable base plate helped the operator to adjust the position of holder with respect to the fruit. The harvesting operation with holder-1 was found to require less effort compared to the existing fruit holder and the other two holders. The holder-2 and 3 were found effective to harvest inclined fruits. The finger like grip provided in these models could grip the inclined fruit tightly and hold the fruits in straight posture prior to cutting.

Comparing the performance of all the models based on time requirement of operation, number of leaves damaged while harvesting, and length of stem cut, the first model i.e., fixed holder with movable base plate provided with 150 mm diameter cutting blade requires less time, 4.54 seconds for harvesting 10 fruits, minimum damage of leaves, 5 nos. while harvesting.

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Pineapple (*Ananas comosus*) is one of the most major fruit crop in the horticultural sector with excellent flavour and remarkable health benefits. Harvesting of pineapple is a tedious process. Manual harvesting of individual fruits is labour intensive and creates more drudgery to the workers. Unavailability of labours and high labour costs are the major crisis in this sector. A pineapple harvesting attachment to brush cutter was developed and tested at Kelappaji College of Agricultural Engineering and Technology in the year 2015-16. It was working satisfactorily for first year crops. The major problem identified with attachment, was the difficulty to move towards fruit due to the dense nature of plant.

Cutting energy and cutting force requirement are some of the vital information in the design aspects of mechanical harvester. Hence, it became requisite to conduct a study on the physical and mechanical properties of pineapple. Physical properties of pineapple plant and fruit were recorded. The cutting energy and cutting force requirement of the pineapple stem and leaves were determined with the help of an impact test apparatus.

The impact test apparatus mainly consists of a base, supporting frame, pendulum arm, cutting blades attached to the free end of pendulum arm, dial gauge, and a vice to hold stem and leaves. The measurements was taken in the field for pineapple stems and leaves.

For the mechanical harvesting of pineapple, three fruit holders were designed to suits to brush cutter. The holder-A supports the fruit and the distance between the cutting edge and holder is fixed. Holder-1 supports the fruit and it can move with respect to the cutting edge. Holder-2 can grip the fruit and it can move with respect to the cutting edge. Holder-3 can grip the fruit but the distance and between the cutting edge and holder is fixed. The field tests of the holders were then conducted to evaluate their performance in comparison with the existing fruit holder.

Conclusions

- The average height of a pineapple plant was obtained as 94.57 cm with a standard deviation of 20.62 cm. The average number of leaves was obtained as 47 with a standard deviation of 13.20.
- The average height of fruit from ground was observed as 33.2 cm and standard deviation 8.6 cm and the average angle of inclination of fruit was 38.2º with a standard deviation of 19.7º. A mature pineapple plant has 0-6 number of suckers.
- The growth of suckers in each of harvesting reduces the visible length of stem and increases the foliar coverage of a single plant.
- The average diameter of stem was 26.69 mm with a standard deviation of 8.57 mm. The maximum diameter of pineapple stem, 43.5 mm was recorded in the first year. The diameter of stem in second and third year doesn’t differ much.
- The fruit dimension including the length, diameter, girth and weight was found decreasing with year of harvesting. The average fruit length was recorded as 21.87 cm with a standard deviation of 8.22 cm.
- There was no significant difference between the values of diameter and fruit weight in first and second year plants, whereas in third year the diameter and weight of fruit decreased.
- The average diameter of fruit was observed as 10.28 cm with a standard deviation of 0.80 cm and average weight observed as 1.17 kg with a standard deviation of 0.32 kg.
- The average moisture content of pineapple stem was obtained as 90.76% with a standard deviation of 1.36%

- The average moisture content of pineapple leaf was obtained as 86.57% with a standard deviation of 1.58%.
- The cutting energy and force requirement of pineapple stem was higher in first year plants than second and third year plants, this was due to the increased diameter of stem in first year plants. The maximum cutting energy and force obtained as 18.10 J and 842.70 N respectively.
- The cutting energy and force requirement of pineapple stem was found increased as the moisture content increases from 89 to 91% and further increase in moisture content caused the decrease in cutting energy and force.
- The cutting energy and force requirement of pineapple leaves was increased with the age of leaves. The older leaves requires maximum cutting energy and force of 9.60 J and 4670.70 N respectively.
- In pineapple leaves, the cutting action was accomplished with the combined effect of bending and shearing. Hence, the cutting force requirement of pineapple leaves was higher than pineapple stem.
- The cutting and force of pineapple leaves was found to decrease as the moisture content increase from 85 to 86%. Thereafter the increase in moisture content leads to the increase energy and force requirement.
- The field evaluation of fruit holders was conducted and it was found that the holder-1 with 150 mm diameter blade requires minimum time for harvesting and minimum damages of leaves. The same combination of holder-blade got first rank in Garret's ranking method.
- The maximum holder efficiency was recorded for the holder-1 among all other holders. It properly holds and safely transferred an average of eight fruits out of 10 fruits harvested.
- In account of operator’s comfort (by Garret’s ranking method) holder-1 got first rank and holder-2 got fourth rank.

- Considering the above discussed points into account the holder-1 was the optimised design.
- The holder-1 and 150 mm diameter combination can harvest 132 fruits per hour.

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CHAPTER VI

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Appendices

APPENDIX A

Table A1. Morphological Details of a Mature Plant

Sl. No	Height of Plant, cm	No. of Leaves (Mature Plant)	Height of Fruit from Ground, cm	Angle of Inclination of Fruit, Degrees
1	92.0	56	46.5	39.8
2	74.0	76	35.0	47.3
3	125.0	35	50.0	17.5
4	80.0	33	39.0	45.3
5	90.0	50	28.0	62.4
6	110.0	35	32.0	12.2
7	70.0	67	45.0	30.6
8	80.0	44	21.0	51.0
9	75.0	25	30.0	67.0
10	105.0	50	22.5	48.0
11	120.0	38	31.5	16.8
12	130.0	42	29.0	26.3
13	75.0	40	26.0	70.3
14	112.5	43	28.0	10.5
15	80.0	45	35.0	28.0
Average	**94.6**	**45**	**33.2**	**38.2**

Table A2. Visible Length of Pineapple Stem

Sl. No.	Visible Length of Stem, cm		
	First Harvest	**First Ratoon**	**Second Ratoon**
1	9.3	10.0	3.5
2	13.2	1.2	1.3
3	10.0	8.0	1.0
4	8.0	5.0	1.2
5	12.0	4.0	1.0
6	6.5	1.0	2.0
7	15.0	4.0	2.1
8	9.2	9.0	3.2
9	12.5	14.0	2.8
10	8.1	7.0	1.1
Average	**10.38**	**6.32**	**1.92**

Table A3. Foliar Coverage of Pineapple Plant

Sl. No.	Foliar Coverage, cm		
	First Harvest	First Ratoon	Second Ratoon
1	75.0	80.0	146.5
2	60.0	100.5	129.6
3	125.0	90.0	145.0
4	110.0	100.0	90.5
5	51.0	120.8	135.0
6	64.0	125.0	150.0
7	48.0	60.2	110.6
8	60.0	130.5	142.0
9	72.0	95.0	120.5
10	117.5	73.0	140.0
Average	**78.25**	**97.50**	**130.97**

APPENDIX B

Table B1. Details of Pineapple Stem

Sl. No.	Stem Diameter, mm		
	First Harvest	First Ratoon	Second Ratoon
1	43.0	19.0	16.0
2	43.0	22.0	16.0
3	34.0	21.5	22.0
4	38.0	26.0	17.3
5	34.0	23.5	15.6
6	40.0	26.0	26.0
7	43.5	24.5	21.5
8	42.0	27.3	18.5
9	34.0	25.0	17.5
10	29.0	26.0	25.0
11	35.0	23.0	22.0
12	37.0	25.5	15.0
13	32.0	21.0	16.8
14	38.0	23.5	19.0
15	36.5	25.0	14.8
Average	**37.27**	**23.92**	**18.87**

Table C1. Details of Pineapple Fruit Harvested (First Harvest)

Period of Ratoon	Fruit Length, cm	Fruit Girth, cm			Fruit Diameter, cm			Fruit Weight, kg
		Top	Middle	Bottom	Top	Middle	Bottom	
1	32.0	31.0	35.0	39.0	9.87	11.15	12.42	1.68
1	33.0	29.0	34.8	36.0	9.23	11.10	11.46	1.48
1	35.0	32.0	34.0	35.5	10.19	10.83	11.31	1.50
1	34.0	29.0	32.8	37.0	9.23	10.44	11.78	1.40
1	33.0	28.0	32.1	36.0	8.91	10.22	11.46	1.36
1	35.0	30.0	34.9	39.1	9.55	11.11	12.45	1.62
1	29.0	29.0	330	34.5	9.23	10.51	10.98	1.16
1	32.0	36.5	37.0	38.5	11.62	11.78	12.26	1.50
1	28.0	27.5	32.0	33.8	8.57	10.19	10.76	1.00
1	36.0	33.0	36.5	37.0	10.51	11.62	11.78	1.56

Table C2. Details of Pineapple Fruit Harvested (First Ratoon)

Period of Ratoon	Fruit Length, cm	Fruit Girth, cm			Fruit Diameter, cm			Fruit Weight, kg
		Top	Middle	Bottom	Top	Middle	Bottom	
2	21.5	32.6	34.0	36.3	10.38	10.82	11.56	1.67
2	19.5	25.8	33.0	34.0	8.21	10.50	10.82	1.17
2	14.5	26.8	30.0	31.0	8.53	9.55	9.87	0.80
2	16.1	27.0	32.6	34.5	8.59	10.38	10.98	1.00
2	18.0	27.0	33.0	34.5	8.59	10.50	10.98	1.12
2	14.5	26.0	31.5	28.6	8.28	10.03	9.10	0.95
2	17.5	28.0	33.0	32.5	8.91	10.50	10.35	1.26
2	21.0	31.2	34.5	36.0	9.93	10.98	11.46	1.52
2	17.0	31.2	32.0	33.0	10.03	10.19	10.50	1.08
2	20.0	32.0	35.5	36.5	10.19	11.30	116.2	1.31

Table C3. Details of Pineapple Fruit Harvested (Second Ratoon)

Period of Ratoon	Fruit Length, cm	Fruit Girth, cm			Fruit Diameter, cm			Fruit Weight, kg
		Top	Middle	Bottom	Top	Middle	Bottom	
3	18.0	23.5	32.0	32.8	7.48	10.19	10.44	1.06
3	13.0	25.0	29.5	30.6	7.96	9.39	9.74	0.94
3	14.5	26.0	29.8	28.0	8.28	9.49	8.91	0.66
3	19.0	24.0	31.5	33.0	7.46	10.03	10.50	1.12
3	13.5	34.0	28.5	30.0	10.82	9.07	9.55	1.08
3	14.5	28.7	31.5	32.6	9.14	10.03	10.38	0.95
3	15.0	29.0	31.5	33.0	9.23	10.03	10.50	1.25
3	16.0	24.5	29.0	30.5	7.80	9.23	9.71	0.73
3	13.0	24.0	26.4	27.5	7.64	8.40	8.75	0.50
3	13.0	24.5	28.0	29.5	7.80	8.91	9.39	0.68

Table C4. Classification of Pineapple Fruit Based on Weight (Class A)

Class	Fruit Length, cm	Fruit Diameter, cm	Fruit Weight, kg
A	25	11.65	1.80
A	21	11.62	1.63
A	22	11.62	1.50
A	21	11.14	1.41
A	20	11.62	1.30
A	21	12.26	1.81
A	19	11.78	1.60
A	24	11.62	1.57
A	22	11.30	1.71
A	21	11.78	1.67

Table C5. Classification of Pineapple Fruit Based on Weight (Class B)

Class	Fruit Length, cm	Fruit Diameter, cm	Fruit Weight, kg
B	19.0	10.35	1.16
B	17.0	11.14	1.16
B	16.0	10.19	1.04
B	16.5	10.50	1.02
B	16.0	10.19	0.94
B	16.0	10.19	1.02
B	18.0	10.67	1.04
B	15.5	10.82	1.08
B	18.0	10.50	1.14
B	17.0	10.83	1.00

Table C6.Classification of Pineapple Fruit Based on Weight (Class C)

Class	Fruit Length, cm	Fruit Diameter, cm	Fruit Weight, kg
C	13.0	9.23	0.62
C	13.0	9.39	0.70
C	13.0	9.07	0.50
C	13.0	9.23	0.64
C	16.0	9.40	0.78
C	13.5	10.30	0.78
C	14.5	10.19	0.78
C	14.5	9.71	0.66
C	13.0	9.87	0.82
C	13.0	9.55	0.66

APPENDIX D

Table D1. Moisture Content of Pineapple Stem in First Harvest

Trail No.	Period of Ratoon	Stem Diameter, mm	Initial Weight, g	Final Weight, g	Moisture Content, %
1	1	43.0	14.3	1.1	92.31
2	1	34.0	9.3	0.9	90.32
3	1	34.0	5.0	0.4	92.00
4	1	34.0	5.2	0.5	90.38
5	1	38.0	5.1	0.3	94.12
6	1	36.0	6.1	0.5	91.80
7	1	37.0	8.0	0.7	91.25
8	1	37.5	7.0	0.5	92.86
9	1	37.0	11.5	0.9	92.17
10	1	34.0	6.2	0.5	91.94
11	1	35.0	5.7	0.5	91.22
12	1	37.0	9.4	0.8	91.49
13	1	32.0	6.5	0.6	90.77
14	1	38.0	7.1	0.8	88.73
15	1	36.5	6.1	0.6	90.16

Sample calculation (Trial No.1)

Initial weight of the sample = 14.3 g

Final weight of the sample = 1.1 g

$$\text{Moisture content (\% wb)} = \frac{W_i - W_d}{W_i} \times 100$$

= ((14.3-1.1)/14.3) x 100

= 92.3%

Table D2. Moisture Content of Pineapple Stem in First Ratoon

Trail No.	Period of Ratoon	Stem Diameter, mm	Initial Weight, g	Final Weight, g	Moisture Content, %
1	2	19.0	27.2	2.20	91.91
2	2	22.0	5.6	0.50	91.07
3	2	25.0	9.8	0.80	91.84
4	2	26.0	6.8	0.80	88.24
5	2	26.5	6.6	0.50	92.42
6	2	26.0	6.6	0.50	92.42
7	2	24.5	6.9	0.70	89.85
8	2	20.5	9.2	0.93	89.89
9	2	27.5	10.2	0.90	91.17
10	2	26.0	7.4	0.50	93.24
11	2	23.0	8.7	0.90	89.65
12	2	25.5	10.0	0.95	90.50
13	2	26.5	6.2	0.67	89.19
14	2	23.5	9.6	0.80	91.66
15	2	24.5	9.7	0.95	90.21

Table D3. Moisture Content of Pineapple Stem in Second Ratoon

Trail No.	Period of Ratoon	Stem Diameter, mm	Initial Weight, g	Final Weight, g	Moisture Content, %
1	3	16.0	19.20	1.40	92.71
2	3	16.0	21.20	1.70	91.98
3	3	22.0	5.80	0.68	88.27
4	3	17.3	12.50	1.10	91.20
5	3	15.6	13.20	1.20	90.91
6	3	26.0	8.80	0.78	91.14
7	3	21.5	9.50	0.79	91.68
8	3	18.5	7.60	0.82	89.21
9	3	17.5	10.00	1.05	89.50
10	3	25.0	6.90	0.65	90.58
11	3	22.0	7.50	0.73	90.26
12	3	15.0	9.60	0.91	90.52
13	3	16.8	7.10	0.84	88.17
14	3	19.0	8.60	0.91	89.42
15	3	14.8	6.80	0.66	90.29

Table D4. Moisture Content of Pineapple leaves (Older Leaves)

Trail No.	Age of Leaves	Leaf Thickness, mm	Initial Weight, g	Final Weight, g	Moisture Content, %
1	Old	5	6.30	0.70	88.88
2	Old	2	5.20	0.86	83.46
3	Old	3	6.60	0.92	86.06
4	Old	5	5.80	0.87	85.00
5	Old	2	6.20	0.87	85.97
6	Old	3	5.10	0.75	85.29
7	Old	4	6.60	0.73	88.94
8	Old	1	5.60	0.78	86.07
9	Old	3	7.10	1.10	84.51
10	Old	4	4.80	0.85	82.29

Sample calculation (Trial No.1)

Initial weight of the sample = 6.30 g

Final weight of the sample = 0.70 g

$$\text{Moisture content (\% wb)} = \frac{W_i - W_d}{W_i} \times 100$$

= ((6.30-0.70)/6.30) x 100

= 88.88%

Table D5. Moisture Content of Pineapple leaves (D-Leaves)

Trail No.	Age of Leaves	Leaf Thickness, mm	Initial Weight, g	Final Weight, g	Moisture Content, %
1	D-leaves	3	5.60	0.80	84.71
2	D-leaves	3	7.00	0.91	87.00
3	D-leaves	2	6.10	0.83	86.39
4	D-leaves	1	5.20	0.79	84.81
5	D-leaves	3	7.60	0.95	87.50
6	D-leaves	3	5.40	0.68	87.41
7	D-leaves	4	6.60	0.91	86.21
8	D-leaves	3	5.80	0.69	88.10
9	D-leaves	2	6.10	0.76	87.54
10	D-leaves	5	6.10	0.74	87.80

Table D6. Moisture Content of Pineapple leaves (Young Leaves)

Trail No.	Age of Leaves	Leaf Thickness, mm	Initial Weight, g	Final Weight, g	Moisture Content, %
1	Young	1	4.70	0.60	87.23
2	Young	2	5.20	0.70	86.54
3	Young	3	6.60	0.730	88.94
4	Young	3	6.90	0.950	86.23
5	Young	2	8.00	1.01	87.38
6	Young	1	7.10	0.83	88.31
7	Young	2	6.50	0.91	86.00
8	Young	1	9.40	1.10	88.30
9	Young	1	6.80	0.86	87.35
10	Young	1	6.80	0.96	85.88

APPENDIX E

Table E1. Cutting Energy and Force Requirement of Pineapple Stem at Node (First Harvest)

Trial No.	Period of Ratoon	Inter node/Node	Stem Diameter, mm	Initial Angle, Degrees	Final Angle, Degrees	Cutting Energy, J	Cutting Force, N
1	1	Node	43.0	90	10.0	15.25	842.66
2	1	Node	43.0	90	15.0	14.96	826.50
3	1	Node	34.0	90	46.0	12.77	751.73
4	1	Node	34.0	90	52.0	11.32	666.24
5	1	Node	43.5	90	25.0	16.67	766.57
6	1	Node	42.0	90	35.0	15.06	717.60
7	1	Node	35.0	90	.45.0	13.01	743.34
8	1	Node	37.0	90	38.0	14.49	783.61
9	1	Node	32.0	90	50.0	11.82	739.07
10	1	Node	36.5	90	38.5	14.39	788.89

Sample Calculation (Trial No.1):

Weight of pendulum arm with cutting blade = 2.35 kg

Average time taken for 10 oscillations = (17.7+18+18.1)/3

= 17.93 s

Period of oscillation, T = 17.93/10

= 1.793

Effective Length, l (From equation 3) = 0.798 m

Diameter of stem, D = 43 mm

Initial Angle = 90º

Final Angle = 10º

Cutting Energy, E = $WgL(\cos \Theta_2 - \cos \Theta_1)$

= 2.35x 9.81x 0.798x (cos 10 - cos 90)

= 18.11 J

Cutting Force, F_{max} = 2E/D

= (2 x 18.11)/ 0.043

= 842.66 N

Table E2. Cutting Energy and Force Requirement of Pineapple Stem at Inter Node (First harvest)

Trial No.	Period of Ratoon	Inter node/Node	Stem Diameter, mm	Initial Angle, Degrees	Final Angle, Degrees	Cutting Energy, J	Cutting Force, N
1	1	Inter node	43.0	90	16.0	17.68	822.51
2	1	Inter node	43.0	90	20.0	17.28	804.05
3	1	Inter node	34.0	90	50.0	11.82	695.59
4	1	Inter node	34.0	90	60.0	9.19	541.07
5	1	Inter node	43.5	90	35.0	15.06	692.85
6	1	Inter node	42.0	90	50.0	11.82	563.10
7	1	Inter node	35.0	90	50.0	11.82	675.72
8	1	Inter node	37.0	90	45	13.01	703.15
9	1	Inter node	32.0	90	55	10.55	659.49
10	1	Inter node	36.5	90	46	12.77	700.24

Table E3. Cutting Energy and Force Requirement of Pineapple Stem at Node (First Ratoon)

Trial No.	Period of Ratoon	Inter node/Node	Stem Diameter, mm	Initial Angle, Degrees	Final Angle, Degrees	Cutting Energy, J	Cutting Force, N
1	2	Node	19.0	90	70.0	4.84	510.27
2	2	Node	22.0	90	76.0	3.42	311.72
3	2	Node	21.5	90	75.0	4.01	372.99
4	2	Node	26.0	90	69.0	6.59	507.13
5	2	Node	24.5	90	65.0	7.77	634.67
6	2	Node	26.0	90	57.0	10.02	770.73
7	2	Node	23.0	90	68.5	6.74	586.29
8	2	Node	25.5	90	70.0	6.29	493.49
9	2	Node	23.5	90	67.0	7.18	311.76
10	2	Node	25.0	90	69.0	6.59	527.42

Table E4. Cutting Energy and Force Requirement of Pineapple Stem at Inter Node (First Ratoon)

Trial No.	Period of Ratoon	Inter node/Node	Stem Diameter, mm	Initial Angle, Degrees	Final Angle, Degrees	Cutting Energy, J	Cutting Force, N
1	2	Inter node	19.0	90	74.5	4.14	435.79
2	2	Inter node	22.0	90	77.5	3.35	304.82
3	2	Inter node	21.5	90	75.0	4.01	372.98
4	2	Inter node	26.0	90	61.5	8.78	675.24
5	2	Inter node	24.5	90	65.0	7.77	634.67
6	2	Inter node	26.0	90	68.0	6.89	530.11
7	2	Inter node	23.0	90	68.0	6.89	599.26
8	2	Inter node	25.5	90	70.0	6.29	493.49
9	2	Inter node	23.5	90	63.0	8.35	710.80
10	2	Inter node	25.0	90	70.0	6.29	503.36

Table E5. Cutting Energy and Force Requirement of Pineapple Stem at Node (Second Ratoon)

Trial No.	Period of Ratoon	Inter node/Node	Stem Diameter, mm	Initial Angle, Degrees	Final Angle, Degrees	Cutting Energy, J	Cutting Force, N
1	3	Node	16.0	90	78.0	2.946	368.35
2	3	Node	16.0	90	70.0	4.84	605.95
3	3	Node	22.0	90	65.0	7.77	706.79
4	3	Node	21.5	90	73.0	5.37	500.34
5	3	Node	25.0	90	70.0	6.29	503.34
6	3	Node	22.0	90	71.5	5.83	530.67
7	3	Node	15.0	90	76.5	4.29	572.61
8	3	Node	16.8	90	78.0	3.82	455.34
9	3	Node	19.0	90	74.5	4.91	517.50
10	3	Node	14.8	90	78.5	3.66	495.63

Table E6. Cutting Energy and Force Requirement of Pineapple Stem at Inter Node (Second Ratoon)

Trial No.	Period of Ratoon	Inter node/Node	Stem Diameter, mm	Initial Angle, Degrees	Final Angle, Degrees	Cutting Energy, J	Cutting Force, N
1	3	Inter node	16.0	90	78.5	2.82	353.22
2	3	Inter node	16.0	90	72.0	4.37	547.048
3	3	Inter node	22.0	90	65.0	7.77	706.79
4	3	Inter node	21.5	90	75.0	4.76	442.92
5	3	Inter node	25.0	90	71.0	5.98	479.15
6	3	Inter node	22.0	90	72.0	5.68	516.81
7	3	Inter node	15.0	90	78.0	3.82	509.98
8	3	Inter node	16.8	90	76.0	4.45	529.82
9	3	Inter node	19.0	90	76.0	4.45	468.48
10	3	Inter node	14.8	90	77.5	3.98	538.07

Table E7. Descriptive of Cutting Energy of Pineapple Stem at Node

Cutting Energy, J				
Period of Ratoon	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
First harvest	11.30	18.10	14.54	2.38
First ratoon	3.40	10.00	6.35	1.90
Second ratoon	2.90	7.80	4.98	1.41

Table E8. Descriptive of Cutting Energy of Pineapple Stem at Inter Node

Cutting Energy, J				
Period of Ratoon	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
First harvest	9.20	17.68	13.10	2.76
First ratoon	3.35	8.78	6.27	1.88
Second ratoon	2.83	7.77	4.81	1.37

Table E9. Descriptive of Cutting Force of Pineapple Stem at Node

Cutting Force, N				
Period of Ratoon	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
First harvest	666.20	842.70	762.62	51.63
First ratoon	311.70	770.70	532.65	130.48
Second ratoon	368.40	706.80	525.658	90.23

Table E10. Descriptive of Cutting Force of Pineapple Stem at inter node

Cutting Force, N				
Period of Ratoon	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
First harvest	541.10	822.50	685.78	88.27
First ratoon	304.80	710.80	526.06	131.51
Second ratoon	353.20	706.80	509.28	90.13

APPENDIX F

Table F1. Cutting Energy and Force Requirement of Pineapple Leaves (Old Leaves)

Trial No.	Age of Leaves	Leaf Thicknes s, mm	Leaf Width, mm	Initial Angle, Degrees	Final Angle, Degrees	Cutting Energy, J
1	Old	5	80.0	90	63.5	9.12
2	Old	2	48.5	90	77.0	4.59
3	Old	3	50.0	90	75.0	5.29
4	Old	5	65.2	90	62.0	9.59
5	Old	2	67.9	90	68.5	7.49
6	Old	3	56.0	90	75.0	5.29
7	Old	4	46.0	90	68.0	7.65
8	Old	1	52.0	90	82.0	2.84
9	Old	3	63.5	90	76.8	4.66
10	Old	4	71.0	90	62.8	9.34

Sample Calculation (Trial No.1):

Weight of pendulum arm with cutting blade = 2.40 kg

Average time taken for 10 oscillations = (18.6+18.8+18.7)/3

= 18.7 s

Period of oscillation, T = 18.7/10

= 1.87

Effective Length, l (From equation 3) = 0.868 m

Thickness of leaves = 5 mm

Initial Angle = 90º

Final Angle = 63.5º

Cutting Energy, E $= WgL(\cos \Theta_2 - \cos \Theta_1)$

$= 2.4 \times 9.81 \times 0.868 \times (\cos 63.5 - \cos 90)$

= 9.12 J

Table F3. Cutting Energy Requirement of Pineapple Leaves (D-Leaves)

Trial No.	Age of Leaves	Leaf Thicknes s, mm	Leaf Width, mm	Initial Angle, Degrees	Final Angle, Degrees	Cutting Energy, J
1	D-Leaves	4	46.5	90	65.3	8.54
2	D-Leaves	3	46.0	90	76.3	4.84
3	D-Leaves	3	10.1	90	78.0	4.24
4	D-Leaves	2	35.0	90	80.0	3.55
5	D-Leaves	5	46.5	90	64.6	8.76
6	D-Leaves	3	42.0	90	75.0	5.28
7	D-Leaves	4	46.0	90	75.5	5.11
8	D-Leaves	4	43.0	90	73.6	5.77
9	D-Leaves	3	38.0	90	78.4	4.11
10	D-Leaves	5	47.8	90	68.6	7.46

Table F3. Cutting Energy Requirement of Pineapple Leaves (Young Leaves)

Trial No.	Age of Leaves	Leaf Thicknes s, mm	Leaf Width, mm	Initial Angle, Degrees	Final Angle, Degrees	Cutting Energy, J
1	Young	1	38.6	90	86.5	1.25
2	Young	3	41.0	90	79.4	3.76
3	Young	3	45.0	90	75.0	5.56
4	Young	3	40.1	90	78.2	4.18
5	Young	2	39.5	90	83.5	2.31
6	Young	2	36.8	90	85.0	1.78
7	Young	1	38.0	90	85.6	1.56
8	Young	3	34.0	90	78.0	4.25
9	Young	2	35.6	90	80.0	3.59
10	Young	1	34.3	90	86.5	1.25

APPENDIX G

Table G1. Time of Operation with Fruit Holder-Blade Combination

Holder-Blade Combination		Average Time of Operation, s	Std. Deviation
Holder 1-150 mm Blade	A	4.54	0.47
Holder 1- 175 mm Blade	B	4.63	0.37
Holder 2-150 mm Blade	C	12.28	0.95
Holder 2-175 mm Blade	D	12.67	0.71
Holder 3-150 mm Blade	E	10.95	0.45
Holder 3-175 mm Blade	F	11.71	0.26
Holder A-150 mm Blade	G	7.48	1.00
Holder A-175 mm Blade	H	6.45	0.96

Table G2. Number of Leaves Cut with Fruit Holder-Blade Combination

Holder-Blade Combination		Average Number of Leaves Cut	Std. Deviation
Holder 1-150 mm Blade	A	5	2.45
Holder 1- 175 mm Blade	B	9	3.81
Holder 2-150 mm Blade	C	11	2.48
Holder 2-175 mm Blade	D	12	2.74
Holder 3-150 mm Blade	E	7	2.61
Holder 3-175 mm Blade	F	9	3.54
Holder A-150 mm Blade	G	8	1.75
Holder A-175 mm Blade	H	9	2.42

Table G3. Length of Peduncle Cut with Fruit Holder-Blade Combination

Holder-Blade Combination		Average Length of Peduncle Cut, cm	Std. Deviation
Holder 1-150 mm Blade	A	5.45	2.45
Holder 1- 175 mm Blade	B	6.34	2.31
Holder 2-150 mm Blade	C	8.13	1.36
Holder 2-175 mm Blade	D	8.68	1.44
Holder 3-150 mm Blade	E	4.77	1.37
Holder 3-175 mm Blade	F	7.07	1.98
Holder A-150 mm Blade	G	7.18	1.77
Holder A-175 mm Blade	H	7.89	1.94

APPENDIX H

Garret's Ranking Method

(a) Factors

H-1: Fixed fruit holder with movable base plate

H-2: Fruit holder with grip and without movable base plate

H-3: Fruit holder with grip and with movable base plate

H-A: Existing holder with fixed base plate

(b) Ranks assigned by operators

Respondent	Ranks			
	H-1	**H-2**	**H-3**	**H-A**
I	3	4	2	1
II	2	3	1	4
III	1	4	2	3
IV	1	4	3	2

(c) Details of rank for each holder

Factor	First Rank	Second Rank	Third Rank	Fourth Rank
H-1	2	1	1	0
H-2	0	0	1	3
H-3	1	2	1	0
H-A	1	1	1	1

(d) Percent Position

$$\text{Per cent position} = 100 \times \frac{\text{Rij} - 0.5}{\text{Nj}}$$

Rank	Percent position, %	Garret Value
First	12.5	72
Second	37.5	56
Third	62.5	43
Fourth	87.5	27

(e) Multiply each rank from section (c) with its Garret's value

Factor	I^{st} x 72	II^{nd} x 56	III^{rd} x 43	IV^{th} x 27	Total
H-1	144	56	43	0	243
H-2	0	0	43	81	124
H-3	72	112	43	0	227
H- A	72	56	43	27	198

(f) Final Rank of Fruit Holders

Factor	Total/ No. of respondents	Average Score	Rank
H-1	243/4	60.75	1
H-2	124/4	31.00	4
H-3	227/4	56.75	2
H-A	198/4	49.5	3

APPENDIX I

Cost Analysis

Fruit Holder-1

A. Basic information

(i) Cost of the fruit holder-1	: 882
(ii) Useful life, year	: 5
(iii) Hours of use per year	: 240
(iv) No. of skilled labours required	: 1
(v) Rate of Interest	: 10%
(Vi) Salvage value (10% of investment cost)	: 88.2
(vii) Field capacity of one holder	: 132 fruits.h^{-1}
(viii) Fuel consumption	: 0.56 l.h^{-1}

B. Various costs

1. Fixed cost

(i) Depreciation cost per year, Rs

$$= \frac{\text{Initial cost - Salvage cost}}{\text{Useful life}}$$

$$= \frac{882 - 88.2}{5}$$

= 158.76

(ii) Interest on investment per year, Rs

$$= \frac{\text{Initial cost + Salvage cost}}{2} \times 0.10$$

$$= \frac{882 + 88.2}{2} \times 0.10$$

= 48.51

(iii) Housing, insurance and shelter per year, Rs = Initial cost x 0.03

= 26.46

(iv) Total fixed cost per year, Rs = 158.76 + 48.51 + 26.46

= 233.73

(v) Total fixed cost per hour, Rs

$$= \frac{\text{Total fixed cost per year}}{\text{Hours of use per year}}$$

= 0.974

2. Variable cost

(i) Repair and maintenance per hour, Rs

$$= \frac{\text{Initial cost} \times 0.5}{\text{Hours of use per year}}$$

= 1.84

(ii) Fuel cost per hour, Rs = Fuel requirement x Fuel rate

= 0.56 x 85.52

= 47.9

(iii) Labour cost per hour, Rs = 200

(vi) Hiring cost of brush cutter, Rs = 100

(v) Total variable cost per hour, Rs = 1.84 + 47.9 + 200 + 100

= 349.74

3. Total cost per hour = Fixed cost + Variable cost

= 0.974 + 349.74

= 350.71

INVESTIGATIONS ON DESIGN PARAMETERS FOR THE DEVELOPMENT OF A PINEAPPLE HARVESTER

By

ATHIRA PRASAD

(2016-18-007)

ABSTRACT OF THESIS

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Abstract

The pineapple (*Ananas comosus*) is a tropical fruit with significant economical importance. The mechanisation in the field of pineapple harvesting has become inevitable. Basic information on its cultivation practices and physical and mechanical properties is essential for the design and development of suitable machinery. Cutting energy and cutting force requirement are some of the vital information in the design aspects of mechanical harvester. As brush cutters have become very common machinery used by farmers and different attachments on brush cutter suitable for harvesting paddy, sugarcane and pineapple have already been developed and are used. Hence, this study is focused on investigation on design parameters for the development of a pineapple harvesting attachment to brush cutter and evaluation of different designs of fruit holders.

The cutting energy requirement was determined using an impact test rig apparatus. The maximum cutting force was then calculated from the cutting energy. For the mechanical harvesting of pineapple, three fruit holders were designed and fabricated. The holder-A supports the fruit and the distance between the cutting edge and holder is fixed. Holder-1 supports the fruit and it can move with respect to the cutting edge. Holder-2 can grip the fruit but the distance and between the cutting edge and holder is fixed. Holder-3 can grip the fruit and it can move with respect to the cutting edge. The field tests of the holders were then conducted to evaluate their performance in comparison with the existing fruit holder.

The average height of a pineapple plant was obtained as 94.57 cm with a standard deviation of 20.62 cm. The average number of leaves was obtained as 47 with a standard deviation 13.2. The average height of fruit from ground

and angle of inclination was observed as 33.2 cm and 38.2º respectively. The average diameter of stem was 26.69 mm with a standard deviation of 8.57 mm. The maximum cutting energy and force of pineapple stem was obtained as 18.10 J and 842.70 N respectively, during the first harvest. In case of pineapple leaves, older leaves require maximum cutting energy of 9.60 J. The field evaluation of fruit holders was conducted and it was found that the holder-1 with 150 mm diameter blade requires minimum time for harvesting, 132 fruits/h, minimum damages of leaves, 5 nos. and more comfortable in handling and operating.

സംഗ്രഹം

ഉയർന്ന വിപണന മൂല്യമുള്ള ഉഷ്ണമേഖലാ ഫലമാണ് കൈതച്ചക്ക (അനാനസ് കോമോസസ്) അതുകൊണ്ട തന്നെ കൈതച്ചക്കയുടെ വിളവെടുപ്പ് പ്രക്രിയയിൽ യന്ത്രവൽക്കരണം അനുവാര്യമായി തീർന്നിരിക്കുന്നു. ഇതിനനുയോജ്യമായ യന്ത്രം രൂപവൽക്കരിക്കുന്നതിന് ഇവയുടെ നടീൽ രീതിയേയും ഭൗതികവും യാന്ത്രികവുമായ സവിശേഷതകളേയും സംബന്ധിച്ച അടിസ്ഥാന വിവരങ്ങൾ ആവശ്യമാണ്. ആവശ്യമായ ഛേദന ഊർജ്ജം, ഛേദന ബലം തുടങ്ങിയവ വിളവെടുപ്പുയന്ത്രത്തിന്റെ രൂപകൽപ്പനയിൽ ആവശ്യമായ പ്രധാന വിവരങ്ങളാണ്. ഇക്കാലത്ത് കർഷകർ സുലഭമായി ഉപയോഗിക്കുന്ന യന്ത്രമാണ് ബ്രഷ്കട്ടർ. നെൽ, കരിമ്പ്, കൈതച്ചക്ക തുടങ്ങിയവ വിളവെടുക്കുന്നതിനായി ബ്രഷ്കട്ടറുകളിൽ അനുയോജ്യമായ മാറ്റങ്ങൾ വരുത്തുകയും ഉപയോഗിക്കുകയും ചെയ്തു വരുന്നു. അതിനാൽ കൈതച്ചക്കയുടെ ഫലപ്രദമായ വിളവെടുപ്പിന് അനുയോജ്യമായതും ബ്രഷ്കട്ടറിൽ ഘടിപ്പിക്കാവുന്നതുമായ ഒരു അറ്റാച്ച്മെന്റ് വികസിപ്പിക്കുമ്പോൾ അതിന്റെ രൂപകൽപ്പനയിൽ ശ്രദ്ധിക്കേണ്ട ഘടകങ്ങളെ കണ്ടെത്തി, ഫലത്തെ താങ്ങിനിർത്തുന്നതി-നുള്ള വ്യത്യസ്ത തരം ഹോൾഡറുകളുടെ വിലയിരുത്തൽ എന്നിവയിലാണ് ഈ പഠനം കേന്ദ്രീകരിച്ചിരിക്കുന്നത്.

ആവശ്യമായ ഛേദന ഊർജ്ജം ഇംപാക്ട് ടെസ്റ്റ് റിഗ് അപ്പാരറ്റസ് ഉപയോഗിച്ചാണ് കണ്ടെത്തിയിട്ടുള്ളത്. ഛേദന ഊർജ്ജത്തിൽ നിന്നാണ് പരമാവധി ഛേദന ബലം കണ്ടെത്തിയത്. കൈതച്ചക്കയുടെ യാന്ത്രിക വിളവെടുപ്പിൽ ഫലം താങ്ങിനിർത്തുന്നതിനായി 3 തരം ഹോൾഡറുകളാണ് രൂപകൽപ്പന ചെയ്തത്. ഹോൾഡർ-1 ഫലത്തെ താങ്ങിനിർത്തു-കയും ഛേദന അഗ്രത്തിനനുസൃതമായി ചലിക്കുകയും ചെയ്യുന്നു. ഹോൾഡർ-2 ഫലത്തെ മുറുകെപിടിക്കുന്നുവെങ്കിലും ഛേദന അഗ്രവും ഹോൾഡറും തമ്മിലുള്ള അകലം സ്ഥിരീ-കൃതമാണ്. ഹോൾഡർ-3 ഫലത്തെ മുറുകെപിടിക്കുകയും ഛേദന അഗ്രത്തിനനുസൃതമായി ചലിക്കുകയും ചെയ്യുന്നു. ശേഷം ഈ മൂന്ന് ഹോൾഡറുകളും കൈതച്ചക്കയുടെ കൃഷിയിട-ങ്ങളിൽ പരീക്ഷിക്കുകയും പ്രവർത്തനമികവിനെ നിലവിലുള്ള ഹോൾഡറുമായി താരതമ്യം ചെയ്ത് വിലയിരുത്തുകയും ചെയ്തു.

ഒരു കൈതച്ചക്ക ചെടിയുടെ ശരാശരി ഉയരം 20.62 സെ.മീ. പ്രാമാണിക വ്യത്യാസ-ത്തോടുകൂടി 94.57 സെ.മീ. യും ശരാശരി ഇലകളുടെ എണ്ണം 13.2 പ്രാമാണിക വ്യത്യാസ-ത്തോടുകൂടി 47 ഉം ആണ് ലഭിച്ചത്. മണ്ണിൽ നിന്നും ഫലത്തിലേക്കുള്ള ശരാശരി ഉയരം, ശരാശരി ചരിവ് എന്നിവ യഥാക്രമം 32.2 സെ.മീ. യും 38.2 ഉം ആണ്. ചെടിയുടെ തണ്ടിന്റെ

ശരാശരി വ്യാസം 8.57 മി.മീ. പ്രാമാണിക വ്യത്യാസത്തോടുകൂടി 26.69 മി.മീ. ആണ്. ആദ്യ വിളവെടുപ്പിൽ പരാമവധി ഛേദന ഊർജ്ജം, ബലം എന്നിവ യഥാക്രമം 18.10 ജ്യൂൾസ് 842.70 എൻ. എന്നിങ്ങനെ ലഭിച്ചു. കൈതച്ചക്കയുടെ പ്രായക്കൂടുതലുള്ള ഇലകൾക്ക് ആവശ്യമായ പരമാവധി ഛേദന ഊർജ്ജം 9.60 ജ്യൂൾസ് ആണ്. ഹോൾഡറുകളുടെ പ്രവർത്തനം വിലയിരുത്തിയപ്പോൾ ഹോൾഡർ-1 ആണ് മികച്ചതായി കണ്ടെത്തിയത്. വിളവെടുക്കുന്നതിന് കുറഞ്ഞ സമയം, 132 ഫലങ്ങൾ/മണിക്കൂർ, ഇലകൾക്ക് കുറവ് കേടുപാടുകൾ - 5 എണ്ണം, സുഗമമായ പ്രവർത്തനം എന്നിവയെല്ലാം ഹോൾഡർ-1 ന്റെ സവിശേഷതകളാണ്.