COCONUT EMBRYO PLUG SCOOPING TOOL

by

HARSHA P (2020-02-004)

NITHYA ROBERT (2020-02-005)

FATHIMA MARIYAM SA ADIYA (2020-02-011)

DILKHUSH GIRI (2020-02-051)

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY, TAVANUR – 679 573,

MALAPPURAM, KERALA, INDIA

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PROJECT REPORT

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DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY, TAVANUR – 679 573,

MALAPPURAM, KERALA, INDIA

2024

DECLARATION

We hereby declare that this project entitled **"COCONUT EMBRYO PLUG SCOOPING TOOL"** is a bonafide record of project work done by us during the course of study and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of another university or society.

HARSHA P (2020-02-004)

NITHYA ROBERT (2020-02-005)

FATHIMA MARIYAM SA ADIYA (2020-02-011)

DILKHUSH GIRI (2020-02-051)

Place: Tavanur

Date:

CERTIFICATE

Certified that the project entitled **"COCONUT EMBRYO PLUG SCOOPING TOOL**" is a record of project work done jointly by Harsha P (2020-02-004), Nithya Robert (2020-02-005), Fathima Mariyam Sa adiya (2020-02-011), Dilkhush Giri (2020-02-051) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to them.

Place: Tavanur

Date:

Guide: Dr. Dhalin D.
Professor,
Dept. of FMPE
KCAET Tavanur.

Co-guide: Dr. Arya K T,
Assistant
Professor(C),
Dept. of FMPE

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Harsha P Nithya Robert Fathima Mariyam Sa adiya Dilkhush Giri

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SYMBOLS AND ABBREVIATIONS

Sl. No.	Abbreviation/Notation	Description
1.	%	per cent
2.	et al.	and others
3.	/	per
4.	i.e.	that is
5.	Fig.	Figure
6.	mm	millimetre
7.	cm	centimetre
8.	m	metre
9.	$mm \cdot s^{-1}$	millimetre per second
10.	N	newton
11.	viz.	namely
12.	$mm \cdot min^{-1}$	millimeter per minute
13.	CAD	Computer Aided Design
14.	mL	millilitre
15.	mAh	milliampere hour
16.	h	hour
17.	m^3	cubic metre
18.	cm^3	cubic centimetre
19.	g	gram
20.	kg	kilogram
21.	rpm	revolutions per minute
22.	$m \cdot s^{-1}$	metre per second
23.	bpm	beats per minute
24.	$N \cdot m^{-2}$	newton per metre square

25.	$kg \cdot m^{-3}$	kilogram per metre cube
26.	SS	Stainless Steel
27.	GDP	Gross Domestic Product
28.	$KJ \cdot min^{-1}$	Kilo joule per minute
29.	$L \cdot min^{-1}$	Liter per minute
30.	AISI	American Iron and Steel Institute
31.	s	Second
32.	G·Pa	Giga Pascal
33.	M·Pa	Mega Pascal
34.	HR	Heart Rate
35.	Hz	Hertz
36.	AC	Alternating Current
37.	N·m	Newton meter
38.	Kg·cm	Kilogram centimeter
39.	V	Volt
40.	W	Watt
41.	DC	Direct current
42.	$J \cdot m^{-2}$	Joule per meter square
43.	VA	Volt Ampere
44.	°C	Degree Celsius
45.	°F	Degree Fahrenheit
46.	DNA	Deoxyribonucleic Acid
47.	RNA	Ribonucleic Acid
48.	CPCRI	Central Plantation Crops Research Institute
49.	CPBMB	Centre for Plant Biotechnology & Molecular Biology

INTRODUCTION

CHAPTER I

INTRODUCTION

Cocos nucifera, known as the coconut palm, belongs to the monocotyledon family Arecaceae (Palmaceae). This subfamily comprises 27 genera and 600 species, with *Cocos nucifera* being the sole species in the genus Cocos (Perera *et al*., 2010). The coconut palm, an economically significant plant in its family, serves both as an ornamental and a food crop. This elegant, slender tree features a fasciculate root system with thousands of roots that grow throughout its lifespan. Tall and stately, the coconut palm can reach a height of approximately 15–30 meters when fully mature (Pham, 2016).

With its exceptional versatility, the coconut serves as a plentiful source of food, household products, and income for approximately 11 million smallholder farmers globally (Beveridge *et al*., 2022). The coconut production was from the data provided by India's Coconut Development Board (CDB), the production of coconut during 2022-'23, in 2019-20 year 2,150.89 million nuts were produced and in 2022-23 it has been increased to 2,277.18 million. India is ranked as the largest producer of coconuts in the world.

The crop is cultivated on 2.08 million hectares (productivity is 11505 nuts per ha). Four major southern states, Kerala, Karnataka, Tamil Nadu, and Andhra Pradesh - contribute to 90 percent of the country's coconut production. Kerala has the largest cultivation area, accounting for 36.89 percent, followed by Karnataka with 25.20 percent, and Tamil Nadu with 22.01 percent (CDB, 2023).

In the fiscal year 2021, coconut contributed nearly 123 billion Indian rupees to the Indian economy (statista, 2021). Additionally, it plays a crucial role in generating foreign exchange earnings of approximately 12 billion for India, while also fostering the growth of subsidiary industries. Moreover, coconut significantly contributes to the national agrarian economy, annually adding around 90 billion to the GDP. Coconut cultivation and processing serve as vital sources of employment for millions of individuals across India. This industry exerts a significant impact on the rural economy by sustaining the livelihoods of approximately ten million people throughout the country (ICAR, 2023).

Conventional methods for seedling production in coconuts face several challenges, including the palm's long juvenile phase, low planting density (Karunaratne

et al., 1989), slow and low fruit production rates that necessitate hand pollination, and variability in seed germination due to unknown triggers. In vitro propagation techniques are being developed to produce cloned plantlets rapidly and in large quantities as an alternative method for generating planting materials. Therefore, improving seed micropropagation techniques in coconuts is essential to increase seedling production (Beveridge *et al*., 2022). Coconut embryo culture utilizes in vitro methods to mass-produce particular coconut varieties (tissue culture) and preserve coconut genetic resources (cryopreservation).

Coconut embryo culture and micropropagation methods offer substantial benefits for coconut breeding initiatives, commercial cultivation, and the distribution of superior coconut varieties (Karun *et al*., 2014). Through exploiting the propagation capabilities of coconut embryos, scientists and farmers can expedite the proliferation of superior coconut genetic resources, thereby advancing genetic enhancement and fostering sustainable yields of this economically vital crop.

Embryo extraction in coconut is done in 11-month-old coconut. Conventionally, embryo scooping is done using tools like sterilized knife (Agbidinoukoun *et al*., 2022), a small metal spoon (Sisunandar *et al*., 2014), tender coconut opener (Sushmitha *et al*., 2019) and embryo plug remover (Mounika Sai *et al*., 2023).

In Central Plantation Crops Research Institute (CPCRI), a tool with serrated tool tip was developed (Devakumar *et al*., 2017), which provides easy penetration of tool into endosperm but after removing the embryo damage percentage is high. The Centre for Plant Biotechnology & Molecular Biology (CPBMB), Kerala Agricultural University, reported that all the mechanical embryo scooping techniques damages the embryo more than 50%, which results in reduction in success rate of embryo culture.

For the precise injury less scooping of coconut embryo, it is necessary to develop a tool which makes less damage to the coconut embryo. In this juncture, development of a coconut embryo scooping tool which makes nearing zero damage to the embryo can access to quality planting materials, such as disease-resistant seedlings and improved propagation techniques viz. tissue culture and embryo culture. Hence the study was undertaken for the development of a motorized coconut embryo plug scooping tool considering human engineering with the following objectives.

OBJECTIVES

1. To study the morphological characteristics of coconut for the systematic design of coconut embryo scooping tool.
2. Design and development of coconut embryo scooping tool.
3. To evaluate different tool geometries for design optimization.
4. To motorize the tool for operational easiness.

REVIEW OF LITERATURE

CHAPTER II
REVIEW OF LITERATURE

The importance of coconut embryo and the tools used for its extraction is reviewed and presented in this chapter under major subsections viz. morphology of coconut, coconut embryo, importance of coconut embryo, mechanical extraction of coconut embryo and ergonomic factor and analysis.

2.1 MORPHOLOGY OF COCONUT

Beccari (1917) was studied about coconut palm. The most widely accepted theory of the origin of this palm is that it is from Asia or Polynesia. The coconut palm was probably transported via ocean currents and occasionally established itself on shores without the aid of man, which would account for its worldwide distribution.

Ochse *et al*. (1961) and Purseglove (1972) described the morphology of the palm. The mature palm is polymorphous, unarmed, unbranched and extends to a height of 60 to 100 feet. It has a life span of about a century. Coconut roots are approximately 8-10 mm in width and 6 m long.

Parrotta (2000) studied about coconut palm. Coconut palm is a tall, erect palm, usually 10 to 20 m in height, coconut has a slender, curved or straight trunk, often, enlarged and inclined at the base, with slightly cracked gray or brown bark.

Purseglove (1972) details the germination process of coconut seeds. Germination commences with the elongation of the cotyledon, guiding the embryo through the fertile eye. Subsequently, the emergence of the plumule and radicle forms the initial root, with the growing shoot tip protected by scale leaves until it produces the first simple leaves upon breaching the exocarp. As the radicle degenerates, adventitious roots develop from the nodes, while the cotyledonary portion within the seed transforms into the haustorium, facilitating nutrient absorption from the endosperm to support seedling growth.

San Andres *et al*. (2023) investigates the properties of coconut fiber and endocarp in Portoviejo and Rocafuerte Cities, Ecuador, with the aim of establishing a knowledge baseline for integrating coconut residues into new material matrices using a circular production approach. Segura *et al.* (2024) studied explores the utilization of natural porous and fibrous materials derived from agricultural and agro-industry waste for acoustic and thermal conditioning in the construction sector. Gunarathne *et al.* (2024)

conducted study on Exploring the prebiotic characteristics of crude polysaccharides from coconut testa flour. Aba *et al.* (2024) conducted a study in the Philippines. This study aimed to assess the physicochemical, nutritional, and antioxidant properties of mature coconut water. Van Dam *et al.* (2004) studied that coconuts are plentiful in coastal tropical regions, with the husk providing a significant source of coarse coir fiber and pith. Detudom *et al.* (2023) investigates the changes in microbiological, physicochemical, and chemical properties of coconut water postharvest, comparing storage at ambient and refrigerated temperatures. Van Dam *et al.* (2006) conducted study for production of compression moulded boards from whole coconut husk the auto-adhesive properties are derived from the intrinsic high lignin content.

2.2 COCONUT EMBRYO

Nair and Anita Karun (1999) made a study on coconut embryo culture and coconut embryo application. Their study showed that, standardization of embryo culture technique provides an easy and safe alternative for the movement of coconut germplasm. Also, application of embryo culture could be for in vitro screening for biotic and abiotic stress. But attention is given only for the matured embryos (about 11 months old) may limit the number of available nuts.

Koffi *et al*. (2013) conducted a comparative study on the morphological and agronomical characteristics of coconut produced from both in-vitro cultured embryo and those originating from seeds. Two years after being planted, the seedlings that were derived from in vitro cultured embryos exhibited significantly reduced growth in terms of height and stem diameter at the base compared to seedlings grown directly from seeds. At the end of 8 year, both plants exhibiting same morphological characteristics, except some minor differences in inflorescence morphology. And also, concluded that the in vitro-cultured embryos can thus be safely employed for the international exchange of coconut germplasm.

Rilo (1999) conducted a study on coconut embryo culture in Makapuno coconut which is rare in the Philippines due to the lack of high yielding true-to-type planting materials. It has a normal embryo; the abnormal status of the surrounding endosperm cannot support its germination and subsequent growth and development. The improved embryo culture technology has been successfully transferred and adopted to mass

produce the Makapuno coconut which does not germinate in situ but has a normal embryo which could be excised and grown in vitro to produce true-to-type Makapuno coconuts.

Vidhanarachchi *et al*. (1997) conducted studies on status of research on coconut embryo culture and acclimatization techniques in Sri Lanka. Study showed that, embryo culture technique has been applied successfully for locally available varieties including tall (ordinary tall, Dikiri and San Ramon forms), dwarf (pumila, eburnea and regia - 3 colour forms), dwarf x tall and tall x tall and germ plasm collecting and exchange, embryo rescue of Dikiri coconuts, in vitro screening for drought tolerant coconut germplasm etc. are some of the applications of coconut embryo culture.

Montero-Cortés *et al*. (2010) studied the CDKA gene in coconut palm, revealing its significant role in cellular regulation during somatic embryogenesis. The findings highlight the gene's increasing expression during embryogenic callus formation, localized within specific cell layers, and its subsequent decrease as somatic embryos progress, culminating in lowest expression levels during germination.

Tammes (1959) conducted a study on nutrients in the giant embryo sac-vacuole of the coconut. The result of the study was many of the nutrients found in the leaf-tissue of the coconut palm can be found in smaller quantities in the vacuole of the embryo sac, with the exception of Potassium which seems to be more evenly distributed in both. Nitrogen in the vacuole was only found in 2 % of the amount present in the wet leaves.

Karunaratne and Periyapperuma (1989) studied the culture of immature embryos of coconut (Cocos nucifera) with a view to developing a technique for clonal propagation. This investigation on the culture of immature embryos indicates that the immature embryo explant is a tissue holding great potential for propagation. The age of the embryo was an important factor determining callus proliferation and subsequent embryogenesis. More than 50% of embryos excised from 6 to 7 month old nuts produced embryogenic callus tissues. Five to six-month-old nuts were not mature enough for excising the embryos. Embryos from older nuts (8 months and above) germinated in culture.

Pech y Aké *et al*. (2004) investigated the germination of coconut zygotic embryos in liquid or solid medium. It was found that germination was more successful when the embryos were cultured in solid medium, when their micropyle end was facing upwards by exposing to ambient atmospheric condition which facilitating germination in anaerobic condition. These findings have important implications for improving protocols

for in vitro coconut embryo culture, ensuring the safe movement of germplasm and conservation of genetic diversity.

Sushmitha *et al.* (2019) conducted research on the effect of Thidiazuron (TDZ) on sliced mature embryo explants through direct organogenesis of coconut var. Chowghat Orange Dwarf (COD). The study concluded that, the treatment Y3 + 150µM TDZ recorded highest shoot induction (90.91 %) and shoot regeneration (72.73 %). A higher concentration of TDZ reduced the frequency of shoot organogenesis.

Tahardi (1985) reported some preliminary results on callus induction and organogenesis in cultures of hybrid coconut embryo. Embryos from mature nuts of Bali x Nias hybrid (KINA II) were initially cultured in a half-strength Eeuweens Y3 liquid medium containing 0.1 mg/1 NAA and 2% sucrose. After 2 weeks in the liquid phase, the embryos were sliced and transferred to a full-strength Y3 agar medium containing 0.2, 1, 5 and 10 mg/1 2, 4-D, 0.25% activated charcoal and 3% sucrose. The embryos cultured in the liquid medium exhibited extensive tissue growth. Subsequently, cotyledonary slices from these embryos, when cultured on agar medium containing higher concentrations of 2,4-D, stimulated the formation of nodular proliferations resembling orchid callus protocorms.

Husin and Suyadi (2015) reported a new breakthrough technique for the production of double seedlings from a single embryo. The technique consists of four steps, viz. germination, incision, splitting and recovery. They concluded that, the most successful recovery process involved splitting the incised embryo into two parts and recovering them in Murashige and Skoog (MS) medium supplemented with IBA and kinetin. Using this protocol, an average of 56 shoots were successfully recovered from 30 zygotic embryos. The study revealed that the meristem tissue of the halved embryo was capable of producing a new meristem and primordial leaf.

2.3 IMPORTANCE OF COCONUT EMBRYO

Sisuandar *et al.* (2014) conducted a study on embryo maturity in cryopreservation. The researchers developed a new four-step cryopreservation protocol and found that embryos isolated from 11-month-old coconut having highest viable embryo (<60%), greater embryo germination rate (40%) and higher percentage of normal seedling (30%). And also, the fruits could be stored for up to 3 weeks prior to embryo extraction without compromising outcomes.

Engelmann *et al*. (2011) developed in vitro culture methods for coconut for large-scale propagation of specific varieties and for international exchange and conservation of coconut germplasm. Two field embryo collection protocols were established, storing embryos in KCl solution or direct in vitro inoculation. For germplasm exchange, inoculated embryos in tubes or endosperm cylinders in bags were used.

Mounika Sai *et al.* (2023) conducted a study on investigating the impact of different plant growth regulators (PGRs) on the early in vitro response of coconut embryos, aiming to overcome the challenges posed by the species' recalcitrance to in vitro manipulations. The study examined four combinations of PGRs: 2,4-D and BA; 2,4-D, BA, and GA3; GA3 alone; and TDZ, alongside a control medium. The results indicate that GA3 and TDZ positively influenced the response of embryos during in vitro culture. Additionally, the expression profiling of cell cycle controlling genes, E2F and CDKA, was conducted using qRT-PCR, with α-tubulin and 18S rRNA genes serving as endogenous controls.

Karunaratne *et al.* (1985) conducted research on the feasibility of in vitro culture for excised embryos of the coconut plant (Cocos nucifera). The study was conducted using embryos, harvested from nuts approximately 10-11 months post-pollination, were subjected to incubation in a modified Y3 medium at temperatures ranging from 30-32°C, accompanied by a 12-hour photoperiod with low light intensity (2.0 $\mu Em^{-2}s^{-1}$). Critical factors influencing the success of embryo culture were identified. A notable observation was the profound impact of sucrose concentration on haustorium development and subsequent root initiation. High sucrose levels significantly stimulated these processes, thereby enhancing overall seedling growth. Furthermore, the presence of activated charcoal emerged as another crucial determinant for success.

Bibble *et al*. (2020), discussed coconut embryo culture (EC), including embryo characteristics, culture methods, and applications in germplasm collection, conservation, elite germplasm exchange, and clonal propagation via somatic embryogenesis. Although embryo culture (EC) allows germination of some coconut varieties that don't germinate naturally, and has been extensively studied, it is not widely adopted. The EC protocols need to be improved to increase survival rates for different coconut genotypes and across different laboratories, especially when transferring plantlets to field conditions. Enhancing embryogenic culture methods is emphasized as essential for maximizing the potential of this fundamental technique in coconut breeding and conservation endeavors.

Zhang *et al*. (2024) studied single-cell RNA sequencing to map the developmental trajectories of coconut embryo cells, identifying key cell types and potential developmental regulators. Notably, quiescent center-like cells were implicated as initiation points for both zygotic and somatic embryogenesis, with CnGRF12 identified as a candidate developmental regulator with potential for enhancing transformation efficiency. These findings offer valuable insights for genotype-independent coconut transformation and gene editing efforts.

Osorio-Montalvo *et al*. (2020) investigated the role of epigenetic mechanisms, specifically DNA methylation, in coconut somatic embryogenesis. The findings demonstrate that pretreatment with 5-Azacytidine (AzaC) significantly enhances early somatic embryo formation and alters the expression profiles of SE-related genes and DNA methyltransferase genes. These results shed light on the regulatory role of DNA methylation in coconut SE, highlighting its importance in modulating gene expression dynamics and morphogenetic changes throughout the process.

Verdeil *et al*. (2001) studied the early cellular reorganization events induced by 2,4-D in coconut calli, elucidating the transition to embryogenic cell individualization and subsequent proembryo development using ultrastructure. Key features such as nuclear envelope invaginations, dictyosome proliferation, and changes in cell wall structure, including callose deposition, suggest parallels with processes observed during the maturation of female gamete cells in plants, providing insights into the mechanisms underlying coconut somatic embryogenesis.

Triques *et al*. (1997) studied the photosynthetic parameters during in vitro development of coconut zygotic embryos into plantlets, revealing similarities and differences compared to autotrophic adult palms. While chlorophyll fluorescence patterns and some photosynthetic parameters show resemblance between in vitro-grown plantlets and autotrophic palms, differences in chlorophyll content and RubisCO capacity suggest a lower photosynthetic efficiency in the former. The establishment of photosynthetic metabolism early in the in vitro development process indicates potential for successful acclimatization of coconut plantlets.

Osorio-Montalvo *et al*. (2020) studied the role of epigenetic mechanisms in coconut somatic embryogenesis (SE). Pretreatment with 5-Azacytidine (AzaC) notably enhances early somatic embryo formation, while affecting DNA methylation levels and

modulating the expression of key genes involved in SE. Increased expression of DNA methyltransferase genes suggests a crucial role for DNA methylation throughout the SE process, offering valuable insights into the regulatory mechanisms underlying coconut SE.

Sabana *et al*. (2020) studies wide profiling of small RNAs to elucidate the molecular basis of coconut's recalcitrance to in vitro culture and the transition of somatic cells to embryogenic calli. Validation of miRNA-target pairs through qRT-PCR and 5′RLM-RACE confirms their regulatory role in somatic embryogenesis, offering insights into potential strategies for enhancing somatic embryo turnover in coconut.

Danson *et al*. (2009) studied the in vitro germination response of zygotic embryos of coconut. The embryos were screened for their germination response on different culture media, and it was found that solid IRD supplemented with activated charcoal enhanced high percentage germination in all tested genotypes. The study also found that disease had no effect on embryo germination, except in one genotype where there was no shoot development in embryos obtained from diseased palms.

2.4 MECHANICAL EXTRACTION OF EMBRYO

Devakumar *et al.* (2017) studied an improved device for coconut embryo extraction. The improved coconut embryo extractor consists of a hollow metallic stainless tube of 25 mm in diameter; 150 mm in length and 1 mm in thickness with serrated margins of 10 mm deep at one end. The improved device works like a metallic protective dome fitting for protecting extracting person’s palm, has a handle for better grip and an ejector mechanism for expelling out the coconut cylinder and kernel waste scraps from the extraction tube. This new device improves the efficiency of embryo extraction and it would be a valuable tool for coconut embryo related experiments.

Stephen *et al.* (2008) were studied the development of an embryo culture manual and an embryo transplantation technique for coconut germplasm movement and seedling production of elite coconut types. The embryo was then removed using a slender scalpel blade which was bent near the tip to help remove the embryo. Using the same blade, the germpore was widened and/or dug deeper when necessary to create a hole to accommodate the foreign embryo. After inserting the foreign embryo, the testa slice was restored to cover the inserted embryo, glue was applied before the shell disk was replaced into its original orientation.

Usually by taking the whole solid endosperm and separating for the embryo is usually followed or by using tools like sterilized knife (Agbidinoukoun *et al*., 2022), a small metal spoon (Sisunandar *et al*., 2014), tender coconut opener (Sushmitha *et al*., 2019), embryo plug remover (Mounika Sai *et al*., 2023) were used.

2.5 ERGONOMIC ANALYSIS

Jain *et al*. (2021) conducted research on identifying musculoskeletal disorders (MSDs) and assess risky postures among workers in small-scale furniture workshops. They redesigned hand tools based on the ergonomic assessment outcomes to improve workers' comfort and reduce MSDs. The ergonomic evaluation highlighted significant issues with current working postures, such as high angles for the upper arm, trunk, and neck. The study successfully identified significant ergonomic issues in small-scale furniture workshops and provided an effective solution by redesigning hand tools.

Yadav *et al*. (2007) studied the comprehensive assessment of the ergonomic aspects and physiological costs associated with using a manually operated six-row paddy transplanter. They measured the energy expenditure rates of male and female operators and determined the physical workload and recommend optimal rest periods during the operation. From the study they concluded that, average energy expenditure was 30.70 kJ/min for male workers and 32.58 kJ/min for female workers, categorizing the task as heavy work. The study found that more force was required for pulling the transplanter (130.32 N for males and 145.12 N for females) compared to handling up and down operations.

Bedny *et al*. (2001) studied a heart-rate methodology to determine the cost-effectiveness of an ergonomics intervention to reduce workload and improve working conditions. The study found that, heart rate analysis is more adequate for evaluating physical work under these conditions compared to energy expenditure analysis. When heart rate exceeds 100 beats per minute, interventions are necessary to reduce workload. If the heart rate is lower than 100 beats per minute, it indicates that the pace and workload can be safely increased.

Singh *et al.* (2021) evaluated the ergonomic impact of using a manually operated chisel weeder in an agricultural field measuring 10 ×10 meters. The focus was on operators aged 25 to 40 years, with various physiological and postural parameters assessed across different age groups and weight samples (1.5, 2.0, and 2.5 kg). They

found that, heart rate, oxygen consumption rate, energy expenditure rate and body part discomfort score were increasing when age groups increased. Heart rate, oxygen consumption rate, energy expenditure rate and body part discomfort score of 20 to 24 year age groups were found minimum and varied from 89 to 108 b/min, 0.32 to 0.555 l/min, 6.96 to 11.49 kJ/min and 17.74 to 21.38 respectively during working. Heart rate, oxygen consumption rate, energy expenditure rate and body part discomfort score of 35 to 39 year age groups were found maximum and varied from 95 to 130 b/min, 0.40 to 0.80 l/min, 8.40 to 16.68 kJ/min and 42.92 to 53.32 respectively operators on paddy transplanter at different weight samples.

Singh (2010) conducted an ergonomic evaluation of a cono-weeder used by farm women in upland rice fields at the Central Institute of Agricultural Engineering (CIAE) in Bhopal. The mean heart rate of the farm women during the weeding operation was 153 beats per minute, with a work pulse of 70 beats per minute. The estimated oxygen consumption rate was 1.0642 liters per minute, equating to 64.7% of the workers' aerobic capacity (VO_{2max}). This high rate indicates that the task is physically demanding and close to the upper limits of sustainable effort for the workers. The study recommends rest breaks and shifting workers to mitigate the physical strain, emphasizing the need for ergonomic interventions to improve the working conditions and health outcomes for farm workers.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The coconut embryo is a crucial component utilized for the propagation of coconut plantations, particularly for developing disease-resistant and high-yielding varieties. However, the current methods for extracting the coconut embryo are inadequate, often resulting in damage to the embryo. Improved techniques are essential to ensure the viability and success of coconut breeding programs. Hence the hypothesis of development of a motorized coconut embryo plug scooping tool has been evolved. The methodology adopted for the systematic development is detailed in this chapter.

3.1 MORPHOLOGY OF COCONUT

3.1.1 Coconut palm

Cocos nucifera known as coconut, coconut palm and palm de coco, is perhaps the most widely recognized and one of the most economically important trees of the tropics. Coconut grows along sandy shorelines throughout the tropics and the most subtropical regions. A tall, erect palm, usually 10 to 20 m in height, coconut has a slender, curved or straight trunk, often, enlarged and inclined at the base, with slightly cracked gray or brown bark. Coconut is widely planted for fruit and as an ornamental and is used throughout its range as a source of food and drink, oil, fibre, fuel, timber, and numerous other products. It is also used in thatching and in other applications as construction material (Parrotta, 2000).

3.1.1.1 Taxonomy

Kingdom	–	*Plantae*
Subkingdom	–	*Tracheobionta*
Superdivision	–	*Spermatophyta*
Division	–	*Magnoliophyta*
Class	–	*Liliopsida*
Subclass	–	*Arecidea*
Order	–	*Arecales*
Family	–	*Arecaeae*

Genus – *Cocos*

Species – *nucifera*

3.1.2 Coconut seed

Coconut seed is surrounded by the endocarp, consists of a thin layer of brown color - the integument – located between the endocarp and the solid albumen. The latter is a fleshy, white and very oily layer, forming a large cavity containing an opalescent liquid or liquid albumen. In the distal part of the seed, where the fruit attaches to the bunch, there are three germination pores and the embryo is under one of them, surrounded by the solid albumen (Frenando *et al.,* 2000).

Branched vascular tubes are observed on the inner wall of the endocarp, which are responsible for conducting elaborated sap through the peduncle, which feeds the albumen. Moisture also penetrates by these tubes during seed germination.

At the beginning of fruit development until the fifth or seventh month after fertilization of the female flower, the central cavity and the liquid endosperm develop. From this age, there are depositions on the walls of this cavity, governed by biochemical processes that incorporate the liquid endosperm to the solid endosperm (Frenando *et al.,* 2000).

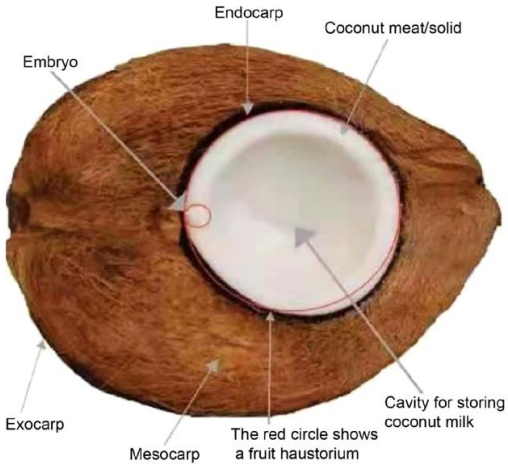


Fig. 3.1 The coconut fruit (Photo: Fernando Cintra)

Cellular endosperm development becomes visible in nuts about 6 months old, at which stage a thin coating of jelly-like endosperm tissue is seen around the periphery of the large embryo-sac cavity. The endosperm tissue is thicker at the antipodal end. The nuclei in the young coconut embryos are diploid (2n = 32), and they divide by normal

mitosis. Nuclei of varying sizes were observed in the endosperm tissue, and they showed very active mitosis, the frequency of division being higher in regions nearer to the micropyle. Three different chromosome counts were made in the dividing nuclei, 48, 96, and 192. This shows that increase in size of nuclei is due to euploid increase in chromosome number. In addition to normal mitosis, a C-mitotic type of division was also observed in the 3n and 6n nuclei, and it is suggested that this type of aberrant mitosis is responsible for the attainment of higher levels of ploidy in coconut endosperm. The solid endosperm (albumen) initially forms in the polar region, opposite to the point of union of the fruit to the bunch, progressively extending throughout the cavity, reaching the greatest thickness at 12 months of age, when the fruit completes maturation. At this stage, the water volume of the fruit is lower than at six months of maturation and the bark acquires dark coloration.

After fruit maturation, seed germination begins, when the embryo undergoes dilation, producing a whitish mass (haustorium), which around five months occupies the entire internal seed cavity (Frenando *et al.,*2000), digesting the albumen to nourish the developing seedling.

3.2 COCONUT EMBRYO

3.2.1 Structure of coconut embryo

The coconut fruit has a small embryo-to-seed ratio (E:S) and a large quantity of endosperm tissue like most palm fruits (Sugimura and Murakami, 1990). Typically, in mature coconut seeds, the endosperm outweighs the embryo by a substantial margin, often reaching approximately 100 times the weight of the embryo. When mature, the coconut embryo has a cylindrical shape of 0.8 cm long (Niral *et al*., 2019). The embryo was about the size of a pea seed under the soft eye of the coconut fruit as it matures. Palm embryos are histologically composed of a short plumular-radicular axis (epicotyl with leaf primordia and hypocotyl-radicle axis) and a large, single cotyledon at the proximal end of the cotyledonary tube (DeMason, 1988).

In coconut embryos, the simple disc of embryonic cells will differentiate into a single cotyledon, and then it differentiates into a tubular base, consisting of a petiole and a distal haustorium (Tomlinson, 1990). The plumule consists of a central meristematic one enclosed by scaly-leaf primordia, which are surrounded by the cotyledonary petiole (Beveridge *et al*., 2022). The radicle is present opposite to the plumule within the apical

mass of meristematic cells positioned near the suspensory region, and it usually differentiates slowly, and can be identified when the primordium grows (Haccius and Philip, 1979). Across various palm species, there exists a remarkable uniformity in the structure and anatomy of their embryos. However, a key point of divergence lies in the orientation of the embryo axis concerning the cotyledon. In most palms, this axis can either align parallel or oblique to the cotyledon. Notably, in the case of coconuts, the embryo axis assumes an oblique orientation relative to the cotyledon, distinguishing it from other palm species.

3.2.2 Importance of coconut embryo

Coconut embryos play a crucial role in propagation, enabling the mass production and clonal multiplication of disease-free coconut varieties. The highly regenerative nature of coconut embryos makes them an invaluable resource for tissue culture techniques and micropropagation. Through embryo culture methods, excised coconut embryos can be induced to germinate and develop into complete plantlets under controlled laboratory conditions (Batugal & Engelmann, 1998). This process allows for the rapid and efficient propagation of desired coconut genotypes, overcoming the limitations of conventional seed-based propagation.

Moreover, coconut embryos can be utilized for clonal propagation, facilitating the production of genetically uniform planting materials. This is achieved by inducing somatic embryogenesis or organogenesis from the embryogenic tissues, leading to the regeneration of multiple plantlets with the same genetic makeup as the parent plant (Samosir *et al*., 1999). Clonal propagation through embryo culture ensures the true-to-type multiplication of superior coconut varieties, preserving their desirable traits and maintaining genetic uniformity across the propagated population.

Coconut embryo culture and micropropagation techniques have significant implications for coconut breeding programs, commercial coconut production, and the dissemination of improved coconut varieties (Karun *et al*., 2014). By harnessing the propagation potential of coconut embryos, researchers and growers can accelerate the multiplication of elite coconut germplasm, contributing to the genetic improvement and sustainable production of this economically important crop.

The existing tools and methods for extracting these embryos are often inadequate, leading to improper extraction and damage to the embryos. Such damage is detrimental, as even a single flaw can compromise the entire propagation process.

3.2.2.1 Tissue culture

Micropropagation of plants under controlled laboratory conditions facilitates the rapid production of numerous clones within a relatively short timeframe. Such micropropagation methods involve less expense and labor compared to conventional cloning techniques (Kyte and Kleyn, 1987).

Coconut palms propagated from seeds exhibit significant variations in productivity, vigor, and disease resistance, typically becoming evident around the age of ten. Consequently, relying solely on seed selection and breeding may not always yield reliable results (Branton and Blake, 1983). Thus, the significance of tissue culture in facilitating vegetative propagation cannot be overstated. Key considerations for tissue culture experiments include the selection of explant material, the mineral composition of the medium, and the prevention of explant browning (Tisserat, 1984). Various plant parts serve as suitable explants, including roots, petioles, leaf tissues, inflorescence rachillae, shoot tips, and embryos. Notably, using meristematic tissues as explants tends to yield more promising results for initiating embryogenic callus (Tisserat, 1979). Zygotic embryos from most palms are particularly effective sources of embryogenic calli (Tisserat, 1984). Additionally, callus derived from the stem and inflorescence of coconut has been documented (Eeuwens, 1976).

In order to obtain maximum yield, a knowledge of the growth patterns and biochemistry of a crop is essential. In vitro clonal propagation allows for the analysis of the growth patterns and biochemical nature of crops, including the palms. Current research should be concerned with improving culture techniques, mass cloning, and determining cell division patterns in culture (Tisserat, 1984). Tissue culture can also be used as a tool for clonal propagation and storage of germplasm of a wide variety of economically important crop plants. Palm callus can be preserved at low temperatures using refrigerants, and later revived to produce plantlets (Ammirato, 1983).

The process of tissue culture of coconut embryos typically involves the following steps:

1. Excision: Mature coconut embryos are aseptically excised from the seeds and surface-sterilized to remove any microbial contaminants (Batugal & Engelmann, 1998).

2. Initiation: The sterilized embryos are inoculated onto a nutrient medium containing plant growth regulators, vitamins, and other essential components (Samosir *et al*., 1999).

3. Shoot and root development: The embryos are transferred to fresh media at regular intervals to facilitate the growth of shoots and roots (Karun *et al*., 2014).

4. Plantlet regeneration: Once the shoots and roots have developed sufficiently, the plantlets are transferred to rooting or acclimatization media to promote further growth and hardening (Fernando & Gamage, 2000).

5. Acclimatization: The regenerated plantlets are gradually acclimatized to ex vitro conditions by transferring them to a greenhouse or growth chamber with controlled humidity and temperature (Batugal & Engelmann, 1998).

Tissue culture of coconut embryos offers several advantages, including rapid multiplication of elite or disease-free coconut varieties, the ability to rescue and propagate embryos from immature or aborted coconuts, and the potential for genetic transformation and improvement of coconut palms.

3.2.2.2 Cryopreservation

Cryopreservation of coconut embryos is a technique used for the long-term storage and conservation of coconut genetic resources. It involves freezing and storing coconut embryos at ultra-low temperatures, typically in liquid nitrogen (-196°C or -320°F), to preserve their viability and genetic integrity for extended periods (Engelmann, 2004).

The process of cryopreservation of coconut embryos typically involves the following steps:

1. *Excision*: Mature coconut embryos are aseptically excised from the seeds under sterile conditions (Sisunandar *et al*., 2010).

2. *Pretreatment*: The excised embryos are subjected to pretreatment processes, such as exposure to cryoprotective agents (e.g., dimethyl sulfoxide, glycerol) or

desiccation, to prepare them for freezing and minimize damage during the cooling process (Engelmann, 2011).

3. *Cooling*: The pretreated embryos are slowly cooled to sub-freezing temperatures, typically using a controlled rate freezer or vitrification techniques, to avoid the formation of ice crystals that can damage the tissues (N'Nan *et al*., 2012).
4. *Storage*: The cooled embryos are then immersed in liquid nitrogen and stored in specialized cryogenic tanks or containers for long-term preservation (Engelmann, 2011).

Cryopreservation allows coconut embryos to be stored for several years or even decades without losing their viability or genetic integrity. This technique is valuable for ex-situ conservation of coconut genetic resources, facilitating the exchange of germplasm between research institutions and breeding programs, and supporting the long-term preservation of endangered or valuable coconut varieties (Engelmann, 2004).

3.3 MECHANICAL EXTRACTION OF EMBRYO

Coconut embryo is taken from coconut of 11-month-old. It is mainly used for embryo culture techniques. The mechanical extraction of embryo is important for the healthy extraction of embryo. Traditionally there is no proper tool for the extraction. Usually by taking the whole solid endosperm and separating for the embryo is usually followed or by using tools like sterilized knife (Agbidinoukoun *et al*., 2022), a small metal spoon (Sisunandar *et al*., 2014), tender coconut opener (Sushmitha *et al*., 2019), embryo plug remover (Mounika Sai et al., 2023). Now a days tools such cork borer (Rillo *et al*., 1991) and some SS cylinders with serrated end are used.

CPCRI has developed an improved coconut embryo extractor comprises a hollow metallic stainless tube measuring 25 mm in diameter, 150 mm in length, and possessing a thickness of 1 mm. Notably, one end of the tube features serrated margins extending 10 mm deep. An ejector mechanism is integrated into the design, facilitating the expulsion of coconut cylinders and residual kernel waste scraps from the extraction tube (Devakumar *et al*., 2017).

In another mechanism, the embryo extraction process involved the use of a slender scalpel blade, carefully bent near the tip to aid in the delicate removal of the embryo from its surrounding tissue. Subsequently, utilizing the same specialized blade,

adjustments were made as needed to widen or deepen the germ pore, creating a suitable receptacle for the insertion of a foreign embryo. Once the foreign embryo was gently placed into the prepared site, meticulous care was taken to restore the testa slice to cover the inserted embryo .

The methods and tools described above typically requires lengthy processing times, leading to fatigue among individuals utilizing these techniques. The efficiency of these tools were considerably low, i.e. during extraction of 10 embryos 2 to 4 healthy injury less embryos survival was reported.

Indeed, the absence of an effectively efficient extracting tool for coconut embryos indicates a clear need for innovation in this area. Introducing a motorized embryo scooping tool could be a promising solution, which significantly reducing the manual labor required and improving the efficiency of the extraction process. By motorizing the extraction process, this device could streamline operations, increase output.

3.4 DESIGN PARAMETERS

3.4.1 Depth of cut

Depth of cut refers to the thickness of solid endosperm present in the coconut seed. Extracting embryos from coconut requires careful handling to avoid damaging the embryo. In essence, the depth of cut in coconut embryo extraction was a critical factor that directly influences the viability, health and success of the extracted embryo. To extract the embryo without damage, a shallow cut has to be made into the endosperm focusing on the largest eye of the coconut. The depth of cut should be enough to penetrate through the endosperm and reach the inner shell without harming the embryo.

3.4.2 Diameter of cut

The diameter of the cut refers to the diameter of the cylindrical plug extracted from the coconut, which encompasses the embryo. The coconut embryo was described as small and cylindrical, embedded in the solid endosperm directly below the functional pore of the endocarp. The embryo was about the size of a pea seed under the soft eye of the coconut fruit as it matures (Pham, L.J., 2016). The coconut embryo has a cylindrical shape.

When mature, the embryo was approximately 8 mm long (Beveridge *et al*., 2022). A typical coconut embryo has an average diameter of 5 mm. To remove the embryo

without causing any damage, adequate clearance for the extraction tool has to be provided. This clearance should ensure that the tool can slides around the embryo without making contact and potentially harming it. Hence, a radial clearance of 5mm was added around the embryo. Consequently, the diameter of the extraction tool needs to accommodate both the embryo and this additional radial clearance. Thus, the total diameter of the tool becomes:

Diameter of tool = (Diameter of embryo) + (2 × Clearance) ……... 3.1

3.5 FORCE MEASUREMENT

3.5.1 Piercing stress

The piercing stress test measures the force required to pierce or puncture a material, such as food products, plastics, or metals. Piercing stress of coconut was important for the design of coconut embryo plug scooping tool. The test results data on the material's resistance to penetration, which is an important indicator of its structural integrity and quality. The piercing force was influenced by factors like the material composition, thickness, and moisture content. The test can reveal how these variables affect the material's piercing stress. The piercing test is related to the principles of shearing, blanking, and punching operations, which involve the deformation, penetration, and fracture of the material.

The test was conducted using a textural analyzer of make: Shimadzu EZ Test, which applies a controlled force to the material until it is pierced. The EZ-SX machine features a robust piercing apparatus meticulously calibrated to exert controlled forces onto test specimens. This apparatus typically consists of a puncture probe or needle, whose dimensions and geometry can be tailored to suit the specific requirements of the material under examination.

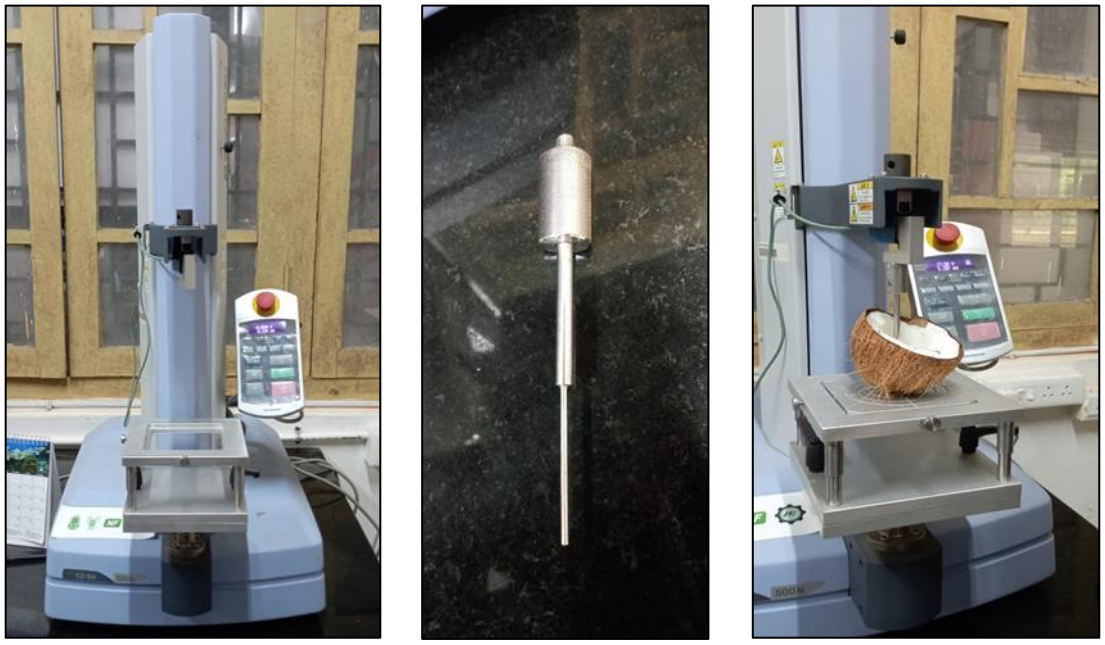
The testing procedure followed:

1. Positioned the half-cut coconut in the testing platform to ensure stability during the assessment.
2. With the coconut in place, the piercing probe was carefully positioned above the target area, ready to initiate the test sequence.
3. Utilizing the EZ-SX machine's intuitive controls, parameters can be specified such as test speed, penetration depth, and data acquisition intervals, thereby

customizing the testing protocol to suit the material characteristics and testing objectives.

4. Once the testing parameters are set, the EZ-SX machine initiates the piercing process, gradually applying force to the coconut through the puncture probe. Here the tool has sharp edge the needle type probe was used for testing.
5. As the probe penetrates the material, the machine continuously monitors and records key metrics such as force exerted, penetration depth, and reaction force.

This real-time data acquisition capability allows for precise measurement of the material's resistance to penetration, enabling comprehensive analysis of its structural properties.



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

Plate. 3.1 Piercing stress measurement

(a) Textural analyzer (b) Probe (c) Experimental setup for piercing strength measurement

Specifications of SHIMADZU EZ-SX Machine:

Tester Load Capacity	- Max. 500 N
Crosshead Speed Range	- 0.001 to 1000 mm/min
Maximum Return Speed	- 1500 mm/min
Dimensions	- W400 × D530 × H885 mm

Weight - Approx. 33 kg

Depth of Test Space - 100 mm (table section)

Power Capacity - 700 VA

3.5.2 Torque

The extraction of embryo encircled endosperm from the half-cut coconut by the tool associated with generating torque. The load torque calculation, crucial for motor selection, involved multiplying the force applied by the distance from the rotational axis.

The experimental setup (Plate 3.2) comprised several key components meticulously arranged for precision and functionality. These included a half-cut coconut, a specialized tool designed for extracting the embryo, a bearing block, a pulley, a digital force analyzer, and a durable rope.

The procedure involved securing the tool onto the coconut's endosperm at one end, while the other end was fastened to the pulley through the bearing block. This arrangement ensured a direct connection between the extraction tool and the pulley, facilitating seamless operation.

Plate. 3.2 Experimental setup for torque measurement

From the experiment it could be calculated that, the value of load at which the coconut meets failure by the shaft.

The value of load from pulley could be converted in to force by the equation

$$F_P = M \times a \qquad \text{……..…...……. 3.2}$$

Where,

M = Load

a = acceleration due to gravity

Bye the torque equation,

$$T = F \times D \qquad \text{…..…….. 3.3}$$

Where,

T = Torque

F = Force

D = Perpendicular distance

Since the forces on pulley and shaft were equal,

$$\frac{T_P}{T_S} = \frac{D_P}{D_S} \qquad \text{…….…...……. 3.4}$$

Where,

T_P = Torque in pulley

T_S = Torque in shaft

D_P = Diameter of pulley

D_S = Diameter of shaft

From this relation the torque required to rotate the shaft can be determined.

3.5.3 Material of construction

The majority of containers, pipework, and food contact equipment made from stainless steel are typically manufactured using either 1.4301 (304) or 1.4401 (316). These grades are preferred due to their excellent corrosion resistance and durability, making them suitable for various food processing applications. Grade 1.4301 (304) stainless steel is widely used in food processing equipment due to its versatility and resistance to corrosion in typical food processing environments. Similarly, grade 1.4401 (316) stainless steel is favored for food processing applications requiring higher corrosion resistance, especially in environments exposed to chloride compounds or acidic foods.

Hence, the stainless-steel grade 304 was selected for making coconut embryo plug scooping tool and also it is corrosion free. So, the tool making is mainly used with stainless steel grade 1.4301 (304).

3.6 DESIGN OF COCONUT EMBRYO PLUG SCOOPING TOOL

3.6.1 Tool tip

Tool tip refers to the very end or point of a cutting tool. This tip is designed to initiate the cutting action by concentrating force onto a small area of the coconut endosperm, thereby enabling penetration and subsequent separation of the material. The design and sharpness of the tool tip are critical for effective and efficient cutting.

Sharpness is defined as the condition of a blade that, under optimal circumstances, ensures a one-dimensional contact between the edge and the material being cut (Schuldt *et al*., 2016). Blade sharpness index (BSI) that relates the energy W_{CI} (Nm) necessary to initiate a cut to the product of cut initiation depth CI (m), thickness x (m) and fracture toughness J (J m^{-2}) of the testing material

$$BSI = \frac{W_{CI}}{CI \cdot x \cdot J} \qquad \text{..... 3.5}$$

When, BSI is 0, indicates a blade with ideal sharpness, and an increase in BSI can be interpreted as decreasing sharpness.

A total of five different tool geometry was tested for its embryo scooping performance as detailed in the forthcoming sessions. The cutting direction was selected as clockwise by considering the ergonomical aspects.

3.6.1.1 Model 1 – Round tool tip

The round tool tip geometry commonly employed for extracting coconut embryos. This extraction tool was fabricated (Fig.3.2) from an outer diameter 20 mm SS 304 pipe. To enhance the efficiency and ease of embryo extraction, the cutting edge of the tool was provided with an inward tapering of length 10 mm, at an angle of 11° at the tip. This tapering geometry enhances the tool penetration into the coconut endosperm.

Fig. 3.2 Model-1 (Round tool tip)

3.6.1.2 Model 2 – Serrated tool tip

The serrated tool tip has the tapering similar to the round tip with a major difference of the cutting section is divided into four teeth (Fig 3.3).

Fig. 3.3 Model-2 (Serrated tool tip)

The tooth geometry was an isosceles triangle of height 20 mm and included angle of 26°as shown in fig. 3.3. This specific angle ensures effective penetration and cutting of coconut endosperm.

3.6.1.3 Model 3 – Saw-tooth tool tip

The saw tooth type tool tip has the tapering similar to the round tip with a major difference of the cutting section is divided into four teeth (Fig 3.4). The teeth geometry was a right-angled triangle (saw-tooth) of height 15 mm and included angle of 34°as shown in fig. 3.4.

Fig. 3.4 Model-3 (Saw-tooth tool tip)

3.6.1.4 Model 4 – Saw tooth tool tip with base slots

The saw tooth narrow tip with base slots has the tooth similar to the saw tooth tip with a major difference of the presence of base slots of width 4 mm in between (Fig 3.5).

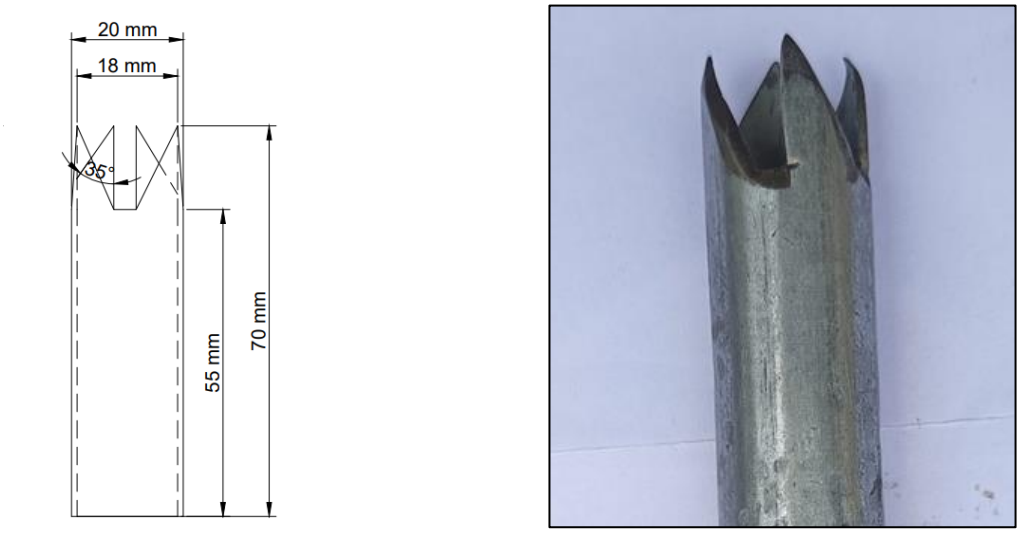


Fig. 3.5 Model-4 (Sawtooth tool tip with gap)

The teeth geometry was a right-angled triangle (saw-tooth) of height 15 mm and included angle of 35°as shown in fig. 3.5.

3.6.1.5 Model 5 – Curved tip

The curved tip has the tapering similar to the round tip with a major difference of the cutting section is divided into four teeth (Fig 3.6). The teeth geometry was a curved (parabolic edge-both inner and outer) tooth of height 15 mm fig. 3.4. The cutting edge of the tool has a stepped cut as shown in the fig to facilitate the effortless scraping of the endosperm, when the tool penetrates into it.

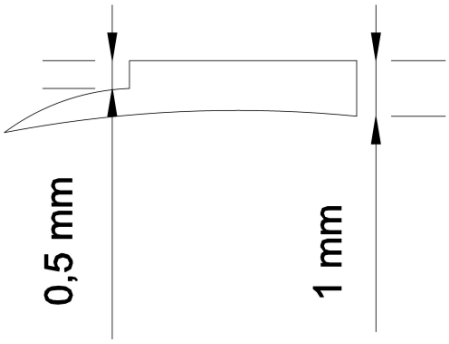


Fig. 3.6 Cross section of step cut

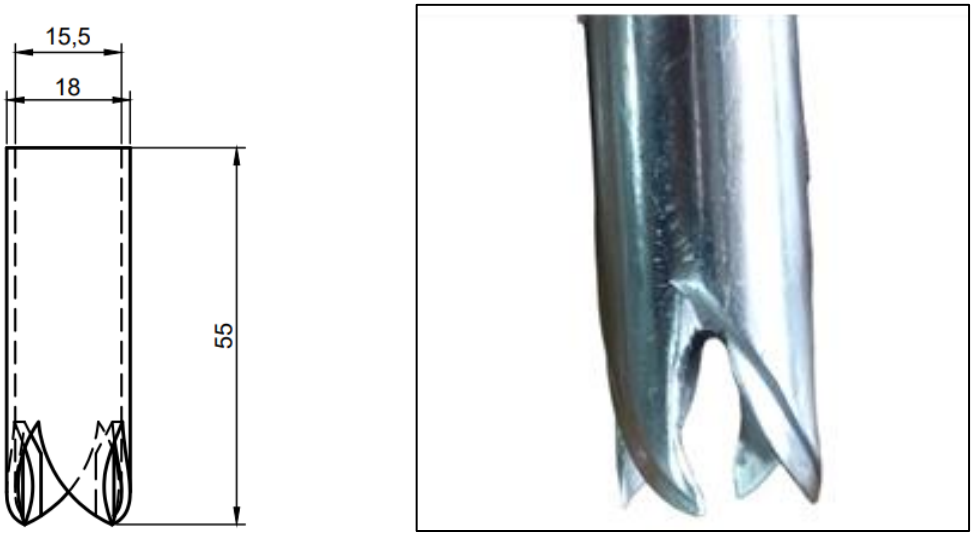


Fig. 3.7 Model-5 (Curved blade tool tip)

3.6.2 Laboratory experiments

3.6.2.1 Scooping efficiency

The scooping efficiency of a coconut embryo extracting unit refers to its capacity to precisely and effectively cut through the coconut shell and endosperm to extract the embryo with minimal damage (Devakumar *et al*., 2017). The efficiency involves the speed at which the tool can complete the extraction process. The tool must be able to maintain a high level of cutting precision and speed consistently throughout the extraction process, without variations that could affect the quality of the extracted embryos. A scientifically designed unit should maximize the number of usable embryos extracted while minimizing losses due to damage or waste.

3.6.2.2 Assessment of embryo damage

The damage to coconut embryos during extraction can vary depending on the tool used. In order to determine the damage to coconut embryo during extraction, five distinct

tool tips were designed, each with variations in the angle and dimensions of their teeth. These variations were carefully made to assess their impact on the embryo. By conducting a detailed analysis of the performance of each tool tip, could measure the extent of damage causing on the embryo by each design. This comprehensive evaluation involves comparing the per cent of damage caused by each tool tip. This process identifies the tool tip which causes the least damage to the embryo.

3.6.2.3 Shape of cut

The shape of cut for the coconut extraction unit is critical to ensuring minimal damage to the coconut embryo. Since the coconut embryo is cylindroid in shape, for its safe extraction, a cylindrical plug of 7.5 mm radially from the center of the embryo has to be scooped out (Fig 3.8).

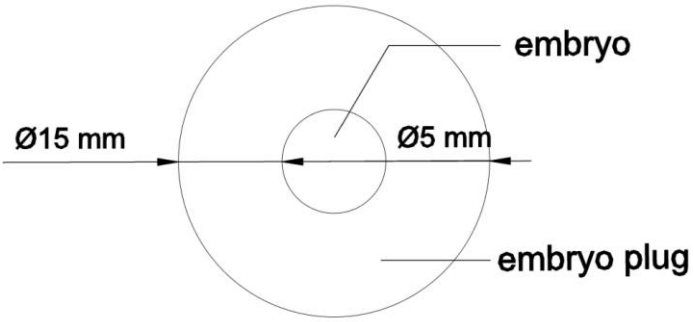


Fig 3.8 Shape of cut

3.6.2.4 Easiness of cut

The ease of cutting of coconut embryo is significantly influenced by the design of extraction tool. The easiness of cut is crucial for ensuring a smooth and efficient extraction process while minimizing damage to the coconut embryo. Factors such as the sharpness of the tool and the moisture content of the endosperm contribute to the overall easiness of the cut.

Easiness of cut for 5 tools could be ergonomically identified by using 3 subjects (persons) by selecting a grade from 1 to 3. 3 represents easy to operate, 2 represents somewhat hard to operate or 1 represents hard to operate.

3.6.2.5 Time of operation

The time required for the scooping of coconut embryos depends on the method of extraction, efficiency of the tools used, and skill of the operator the time of operation was recorded with the help of a stopwatch.

3.6.3 Prototype tool tip

Five different tool tip models with distinct geometric features and dimensions for laboratory testing. Laboratory tests (section 3.6.2) revealed that model no. 5 and model no. 3, were superior in extracting the coconut embryo compared to the rest of the models.

For the final tool prototype, model -5 (curved tip) was selected due to its better finish of cut and faster operation. The features and dimensions of the final prototype were listed below,

i. Outer diameter :18 mm

ii. Inner diameter :15.5 mm

iii. Number of blades : 4

iv. Length of blade : 15 mm

v. Shape of blade : Curved with step cut

Plate. 3.3 End of cutting edge

3.6.4 Embryo plug ejection unit

The coconut embryo plug formed during the process gets retained inside the cylindrical cavity of the tool. In order to facilitate the easy and safe removal of the embryo plug, an integrated ejection mechanism was developed.

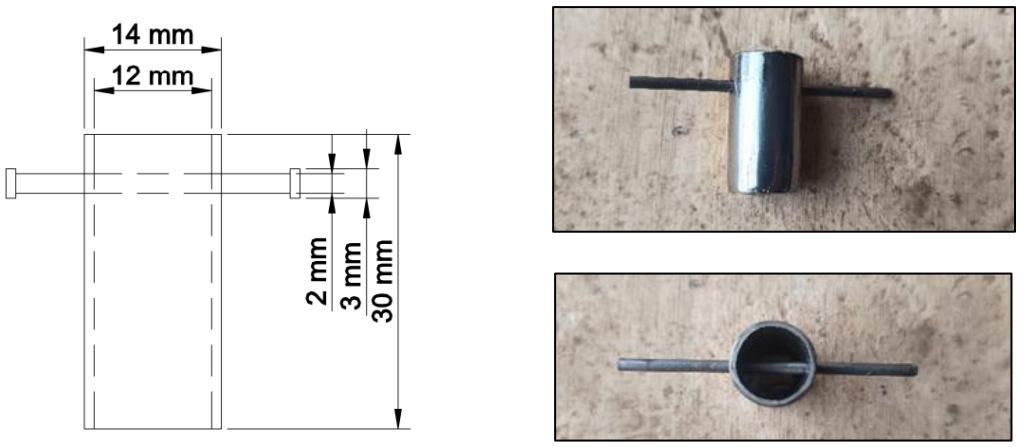


Plate. 3.4 Embryo ejection unit

The ejector mechanism consists of an internal plunger unit with diametric probes for free co-axial movement with respect to the tool. The cylindrical shaped ejector having a length of 30 mm and diameter 14 mm. The probe was diametrically fixed at a distance of 27 mm from the head of the ejector. The probe having a diameter of 3 mm and length of 7 mm. the stroke of the plunger is governed by a linear slot on the tool in which the probe slides.

3.6.5 Electric drive system

The embryo plug scooping operation is repetitive and monotonous. While scooping the plug the operator has to hold, push and turn the tool, simultaneously the operator has to secure the half-cut coconut in position to avoid embryo damage. The scooping operation requires significant pushing and turning efforts which results in the fatigue. This fatigue leads to pain in the palmar region (particularly beneath the fingers and adjacent to the thumb), wrist, elbow joint and shoulder of the operator. In order to make the scooping operation operator friendly, especially for women an electric drive mechanism was introduced.

3.6.5.1 Electric motor drive

Planetary gear motor was selected as a prime mover. Since, it has a coaxial output shaft and robust operation which is most essential to reduce the operator fatigue.

A planetary gear motor is a type of gear system used to deliver high torque and speed reduction in a compact, efficient package. It consists of three main components: the sun gear, the planet gears, and the ring gear.

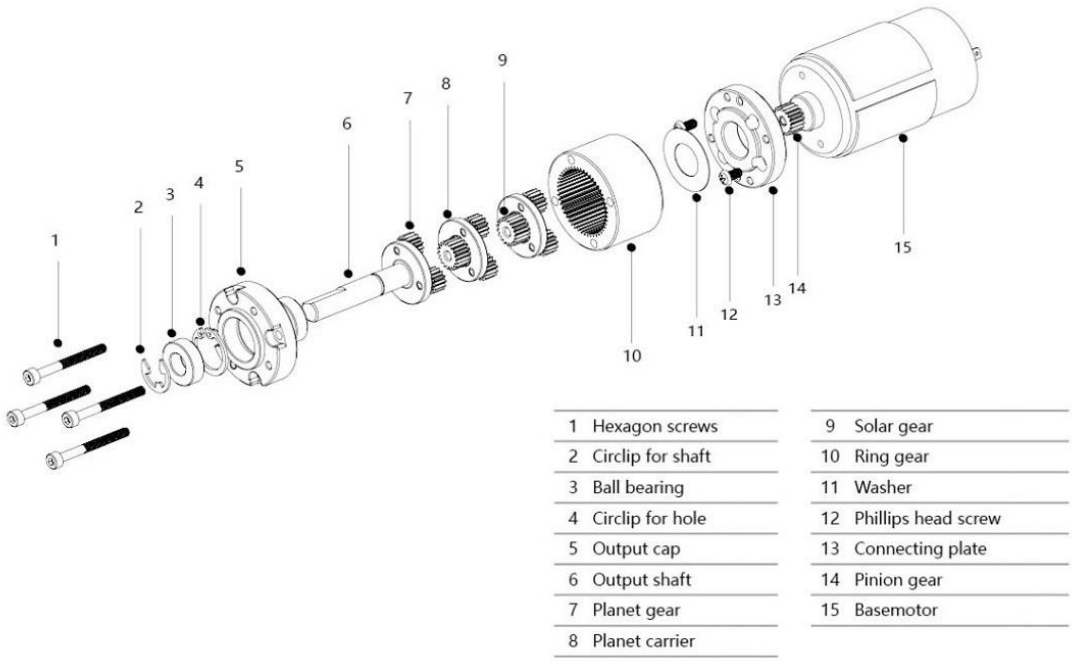


Fig. 3.9 Structural arrangement of planetary gear motor

Working principle:

When the motor drives the sun gear, it rotates and transmits motion to the planet gears. These planet gears revolve around the sun gear while simultaneously rotating on their axes. The planet gears, in turn, mesh with the stationary or movable ring gear, creating multiple points of contact which distribute the load more evenly and provide high torque.

Features:

i. High Torque Output

ii. Compact Design

iii. Efficiency

iv. Durability

Specifications:

i. Power : 7 W

ii. Voltage : 12V DC

iii. Gearbox & Motor Dia : 36 mm

iv. Base Motor RPM : 5000 rpm

v. Gear Breaking Torque : 80 kg·cm (8 N·m)

vi. Gearbox Reduction Ratio : 139

vii. Backlash : ≤2º

viii. Bearing Used : Ball bearing

ix. Gearbox Material : Zink Alloy

x. Weight : 350 g approx.

Fig. 3.10 Planetary geared DC motor

The power from the AC mains is converted to 12 V, 5 A DC using a power adapter with following specifications.

Specifications:

Brand	: SAMCOM
Input voltage	: 220 V
Output voltage	: 12 V
Wattage	: 60 W
Current rating	: 5 A
Frequency range	: 50 to 60 Hz
Main power connector type	: 2 pins

Features:

i. Light weight design

ii. Short circuit protection

iii. Water proof

iv. Over current protection

v. Over voltage protection

vi. Over temperature protection

vii. Pin size: 5.5×2.5 mm

viii. Adapter size: 113×50×31 mm (length × width × height)

Fig. 3.11 Power adapter and connector

3.7 CAD IN SOLIDWORKS AND FORCE ANALYSIS

A systematic software design analysis was also performed for structural stability subjected to induced stress and strain. SolidWorks® 2019-2020 is a 3D computer-aided design (CAD) software used for designing and modelling mechanical components and products. SolidWorks enables to create 3D models using a wide range of tools and features, including sketching, extruding, sweeping, lofting, etc. These models can be modified in real-time, allowing for rapid prototyping and iteration. In addition to modelling, SolidWorks also offers a range of tools for analyzing and testing designs, such as simulation, motion analysis, and stress testing. This ensures that the prototype would function as intended and withstand actual operational conditions.

Constraints were added to the model for the static analyses such as fixtures and loads, to simulate working conditions. Those analyses help to determine how the model will behave under different conditions, such as different loads and to optimize the design accordingly. SolidWorks also provides a range of visualization tools, including contour plots and deformation animations, that visualize the results of analysis and better understand the behaviour of the model.

3.8 PHYSIOLOGICAL ASSESSMENT

Any biomechanical activity involves muscular actuations causing stress on the cardio-pulmonary system. By monitoring the cardio-pulmonary parameters of an individual performing a certain task, the degree of physiological stress could be assessed (Plate 3.9). This also helps in evaluating an activity or task for energy requirement and determination of efficient method of performing a given task.

Plate. 3.5 Evaluation of coconut embryo plug scooping tool in lab

Physiological stress measurement parameters:

i. Heart rate

ii. Oxygen consumption and Energy expenditure

iii. Core temperature

iv. Blood lactic acid level

v. Blood pressure

Physiological energy expense involved in any operation is expressed in terms of cardiorespiratory response of the subjects during the work, reflecting variations in heart rate and oxygen consumption rate. Heart rate integrates the total stress on the body and can be used as an index of the physiological cost of work.

Heart rate as a primary indicator of circulatory function and oxygen consumption, representing the metabolic conversion taking place in the body could be monitored using heart rate sensor (fig. 3.12). It has linear and reliable relationship with the oxygen consumption rate which response quickly to the change in work demand (Kroemer *et al*., 1997).

Fig. 3.12 Heart rate sensor

Specifications:

Make and Model	:	Polar Electro Oy – Model H10
Dimensions	:	Width: 65 mm Height: 34 mm Thickness: 10 mm
Weight	:	Total weight: 60 g Total weight without wristband: 21 g
Durability	:	Operation temperature min. -10°C Operation temperature max. 50°C Water resistance: WR30
Battery	:	Battery capacity: 165 mAh Battery type: lithium primary battery 3V

The data of maximum heart rate and average heart rate were obtained using a portable heart rate sensor with mobile application. The oxygen consumption for the male

and female subject should be calculated differently. The oxygen consumption rate can be calculated for both male and female subjects using the following empirical equations.

For male subjects, oxygen consumption can be find using the equation,

$$Y = 0.014\,HR - 0.80 \qquad \text{…….. 3.6}$$

For female subjects, oxygen consumption can be find using the equation,

$$Y = 0.11\,HR - 0.59 \qquad \text{…….. 3.7}$$

From the obtained data of oxygen consumption, the energy expenditure by the subjects can be find out using the equation,

$$E = 20.9 \times Y \qquad \text{……. 3.8}$$

For finding VO_2max, maximum heart rate is found out using the equation,

$$HR_{max} = 190 - (\text{Age in years} - 25) \times 0.62 \qquad \text{…….. 3.9}$$

Then VO_2max is finding using the above equation for both male and female subjects.

3.8.1 Discomfort analysis

Comfort is a critical aspect of hand tool ergonomics, as it is often evaluated to predict and mitigate the risk of musculoskeletal injuries, which should always be minimized. In the context of hand tool usage, comfort is linked to positive attributes such as reliability, safety, ease of use, and user satisfaction. Conversely, discomfort is associated with negative sensations, including pain, pressure, rigidity, and irritation (Jansen *et al*., 2013).

Discomfort in different regions of the hand was subjectively estimated for both hand tools and motorized tool.

RESULTS AND DISCUSSION

CHAPTER IV
RESULTS AND DISCUSSION

A coconut embryo plug scooping tool was designed, fabricated and evaluated. The results of the studies on its scooping efficiency, forces acting and the ergonomic aspects were recorded, analyzed in this chapter.

4.1 THE DESIGN OF TOOL

4.1.1 Depth of cut

Depth of cut is influenced by the length of blade used for the scooping process. The average depth of cut (thickness of endosperm) of different coconut samples are recorded and presented in table 4.1. If the length of tip of tool was not equal to or more than the depth of cut, then the cutting efficiency of the tool will decrease.

Table. 4.1 Depth of cut (thickness of endosperm) of coconut samples

Sl. No.	Coconut sample	Thickness of endosperm (mm)
1.	Sample 1	13.5
2.	Sample 2	13.4
3.	Sample 3	14.0
4.	Sample 4	13.2
5.	Sample 5	12.0
6.	Sample 6	13.6
7.	Sample 7	13.5
8.	Sample 8	13.8
9.	Sample 9	13.0
10.	Sample 10	13.1

The maximum depth of cut was observed as 14 mm. hence, the length of tool tip was selected as 15mm

4.1.2 Diameter of cut

A typical coconut embryo diameter was observed as 5 mm. The diameter of the cut refers to the diameter of the cylindrical plug scooped, which encompasses the embryo.

To avoid damage of embryo during scooping, a plug of endosperm has to be attached with it as a protective cover. Hence, the diameter of cut of the cylindrical plug to be scooped from the coconut was set to be cylindrical in shape with diameter 15 mm as the embryo at the center.

Diameter of tool = (Diameter of embryo) + (2 × Clearance)

= 5 + (2 × 5)

= 15 mm

This ensures when a cut is made for scooping it provide sufficient safety and protection to the embryo from damage.

4.2 FORCE ANALYSIS

4.2.1 Piercing stress

The force required for piercing the needle probe of diameter 3 mm was experimented with textural analyzer make: EZ-SX machine by Shimadzu. The data observed were shown in table 4.2. The piercing force was measured at a speed of 150 mm/min.

Table. 4.2 piercing stress measurement of coconut endosperm

Sl. No.	Parameters	Piercing force (N)
1.	1 _ 1	30.3005
2.	1 _ 2	24.9706
3.	1 _ 3	22.4587
4.	1 _ 4	36.7906
5.	1 _ 5	33.9441
6.	1 _ 6	32.2654
7.	1 _ 7	28.5784
8.	1 _ 8	23.2682
9.	1 _ 9	25.6759
10.	1 _ 10	36.5978

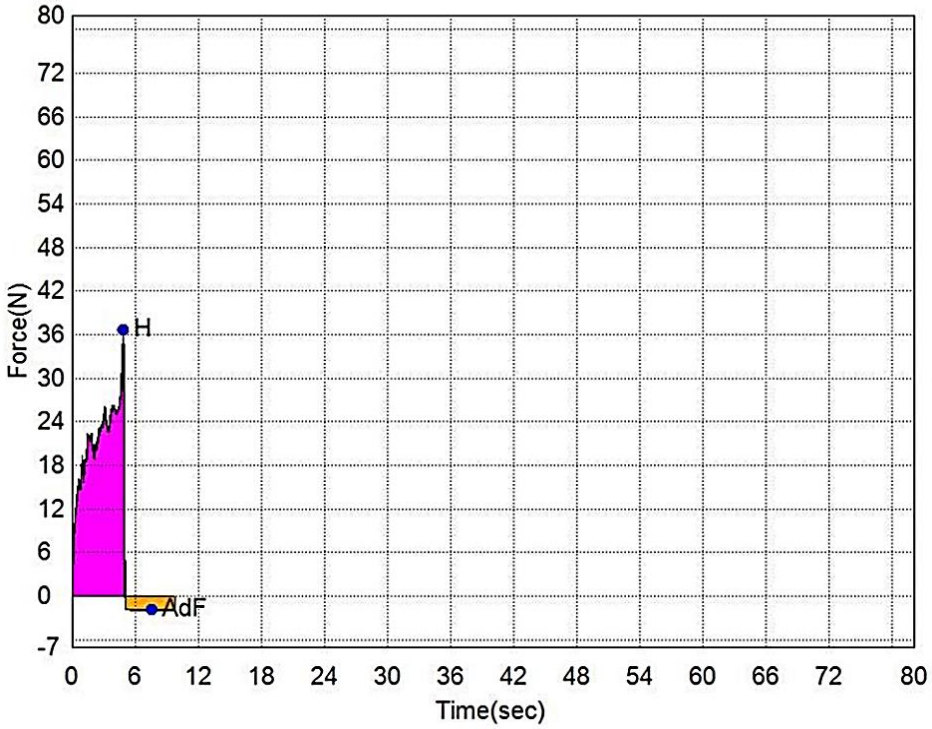


Fig. 4.1 Force vs. time graph

From the figure 4.1 the average value of maximum force required for piercing was observed to be 29.6850 N, with a standard deviation is 5.66464 N. Also, the maximum force recorded for piercing the coconut endosperm was 36 N. Hence, for the design of tool the maximum expected force at the tool tip was taken as 38 N.

4.2.2 Torque

The torque for cutting the endosperm by the designed tool was measured with the experimental setup made as detailed in section 3.5.2. The measured load was converted to corresponding torque and was presented in table 4.3.

Table. 4.3 Measured loads during the experiment

Sl. No.	Load (kg)	Torque (N·m)
1	0.8	0.148
2	1.3	0.24
3	1.1	0.20
4	1.2	0.223
5	1.25	0.233

The maximum torque was calculated for the corresponding load 1.3 kg.

From the equations

$$F_P = 1.3 \times 9.8$$

$$= 12.75 \text{ N}$$

$D_P = 4.4$ cm. Then,

$$T_P = 12.75 \times 4.4$$

$$= 56.1 \text{ N} \cdot \text{cm}$$

$D_s = 1.9$ cm

By the relation,

$$\frac{56.1}{T_s} = \frac{4.4}{1.9}$$

Then,

$$T_s = 24.23 \text{N} \cdot \text{cm}$$

$$= \mathbf{0.24 N \cdot m}$$

By considering the factor of safety the torque requirement was 0.24 × 3 = 0.72 and the available planetary motors, which can exert the force more than 0.72 N was selected as prime mover for the instrument in market, the motor with 1.5 kg cm was chosen.

4.3 LAB STUDIES FOR THE OPTIMIZATION OF TOOL TIP

4.3.1 Shape of cut

The coconut embryo was extracted in cylindrical shape of an average diameter 5 mm normally.

(a) **(b)**

Plate 4.1 (a) Coconut Plug (b) Coconut embryo

To extract the embryo without damage, a plug of endosperm encircled embryo has to be scooped out. Hence, the shape of plug is cylindrical with diameter 15mm and height varies with the thickness of endosperm (13 mm to 15 mm). Accordingly, 5 tool tips were designed and evaluated (Model - 1 to Model - 5) for its scooping efficiency. The curved tool tip shown perfect cylindrical shape of cut.

4.3.2 Easiness of cut

The ease with which the tool enters into the endosperm and performs the cutting action was evaluated for different subjects and their grading was recorded and presented in table 4.4.

Table 4.4 Easiness of cut - Grade for different tool tips.

Tool name	Subject 1	Subject 2	Subject 3	Total grade
Round tip	1	1	2	1
Serrated tip	2	2	2	2
Saw- tip	2	3	2	2
Saw tip with gap	1	1	1	1
Curved tip	3	3	3	3

It was observed that the curved tool tip performed easy penetration and scooping of embryo plug from the coconut and it was selected for the final prototype fabrication.

4.3.3 Time of operation

Time of operation refers to the time of operation of the tool for the removal of coconut embryo plug. All the 5 model tool tips were evaluated and the time required to scoop out the embryo plug was recorded and presented in table 4.5.

Table. 4.5 Time of operation for different tool tips

Sl. No.	Type of tool	Time of operation (s)
1.	Round tip	29
2.	Serrated tip	21
3.	Saw-tooth tip	17
4.	Saw-tooth with gap	19
5.	Curved tip	12

It was observed that the curved tool tip performed minimum tool requirement for successful embryo scooping. Hence, the selection of curved tool tip was justified.

4.3.4 Damage of embryo

Damage of embryo depends not only the shape and sharpness of tool tip but also the skill and the experience of the operator about the position of embryo in the endosperm and its extraction.

Table. 4.6 Percentage damage of coconut embryo

Sl. No.	Type of tool tip	Percentage damage (%)
1.	Round tip	60
2.	Serrated tip	80
3.	Saw-tooth tip	40
4.	Saw-tooth with gap	80
5.	Curved tip	10

The percent damage for 5 models tool tips were evaluated and presented in table 4.6. It was concluded that the percentage damage was minimum (10%) for the curved tip and hence it was selected for final prototype fabrication.

4.3.5 Scooping efficiency

The scooping efficiency of a coconut embryo extracting unit refers to its capacity to precisely and effectively cut through the coconut endosperm and extract the embryo with minimum damage.

Table. 4.7 Scooping efficiency for different tool tips

Sl. No.	Type of tool tip	Total number of trials	Successful trials	Scooping efficiency, %
1.	Round tip	10	2	20
2.	Serrated tip	10	4	40
3.	Sawtooth	10	7	70
4.	Sawtooth with gap	10	5	50
5.	Curved tip	10	9	90

The scooping efficiency for 5 model tool tips were recorded and presented in table 4.7. it was observed that curved tool tip performs maximum scooping efficiency (90%).

The curved tool tip was found to be ideal for embryo plug scooping with its better performance in shape of cut, easiness of cut, time of operation, minimum damage of embryo and scooping efficiency. The overall higher performance in comparison with other 4 models may be due to

i. The sharpness of the blade enhances the penetration and cut of the endosperm
ii. The Curved shape of cutting edge easily expels out the grind endosperm while penetrating into it. In other cases, the ground material offers resistance to the further penetration and cut which leads to the reduction in performance of those models.
iii. The scooping and holding capacity were maximum for curved shaped blade due to its peculiarity in geometry.

4.3.6 Effect of moisture content of coconut endosperm on time of operation

The correlation between time of operation and moisture content was recorded, analyzed and presented in fig 4.2.

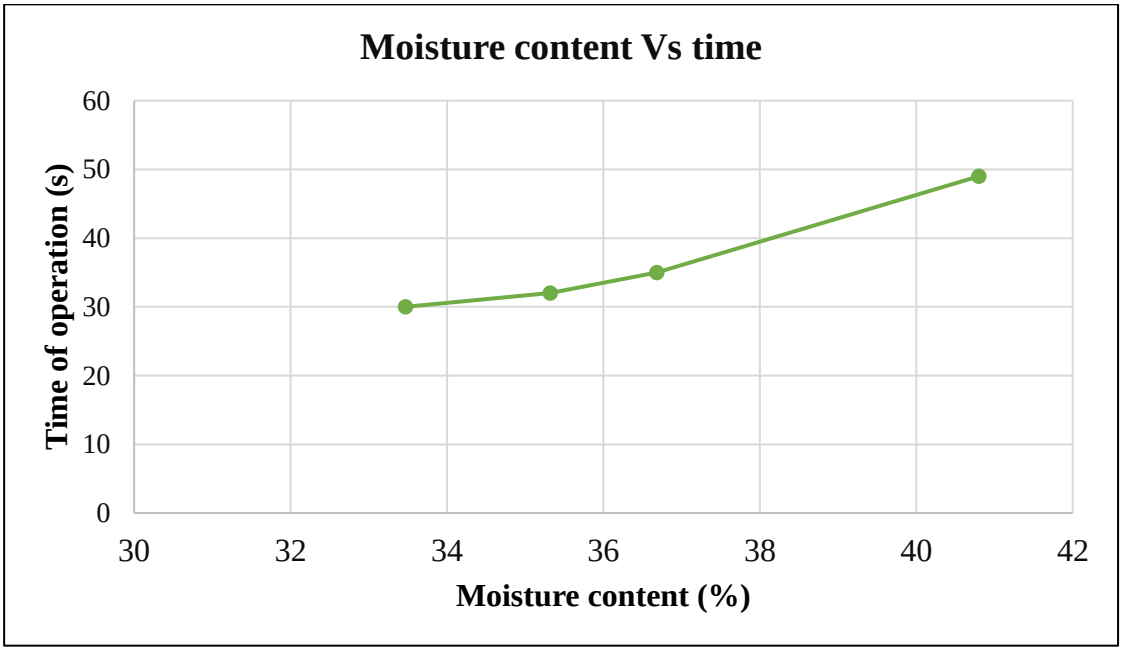


Fig. 4.2 Effect of moisture content on time of operation

It was observed that the time of scooping increased with moisture content. The time required for the extraction of a coconut embryo decreases as the moisture content decreases. This was because, as moisture content decreases, the coconut tissue becomes harder and more brittle. Lower moisture content results in reduced adhesion between the

coconut shell and the endosperm. It makes easier to separate the shell from the embryo, as there was less water acting as a bonding agent.

4.3.7 Effect of tool tip geometry on Scooping capacity

Scooping capacity refers to the amount of work an equipment can complete within a given time frame, usually one hour.

Table. 4.8 effect of different tool tips on Scooping capacity.

Type of tool tip	Scooping capacity (number of plugs per hour)
Round tip	124
Serrated tip	171
Saw-tooth tip	211
Saw-tooth with gap	189
Curved tip	300

The scooping capacity of different geometry of tool tips were evaluated, analyzed and presented in fig 4.3

The curved tip performed the maximum scooping capacity of 300 Number/hr.

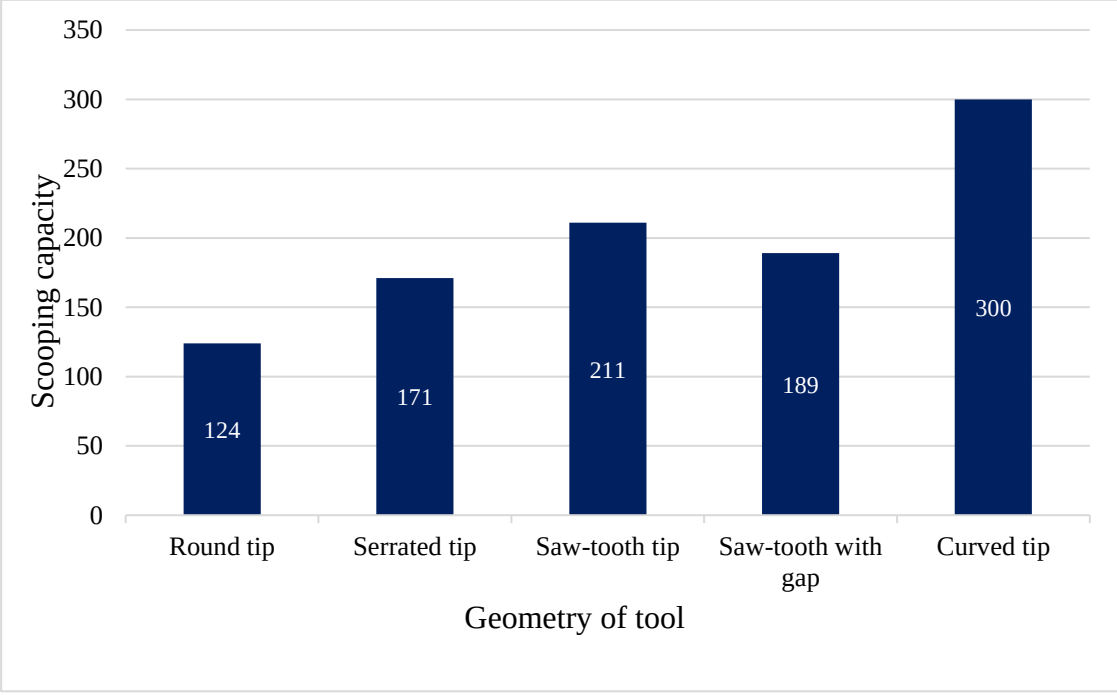


Fig. 4.3 Scooping capacity of different tool tips

4.4 FORCE ANALYSIS USING SOLID WORKS

The force analysis was done to the curved tool tip made from SS 304 considering piercing force and torque obtained during experiments for comparing stress, strain and displacement under load.

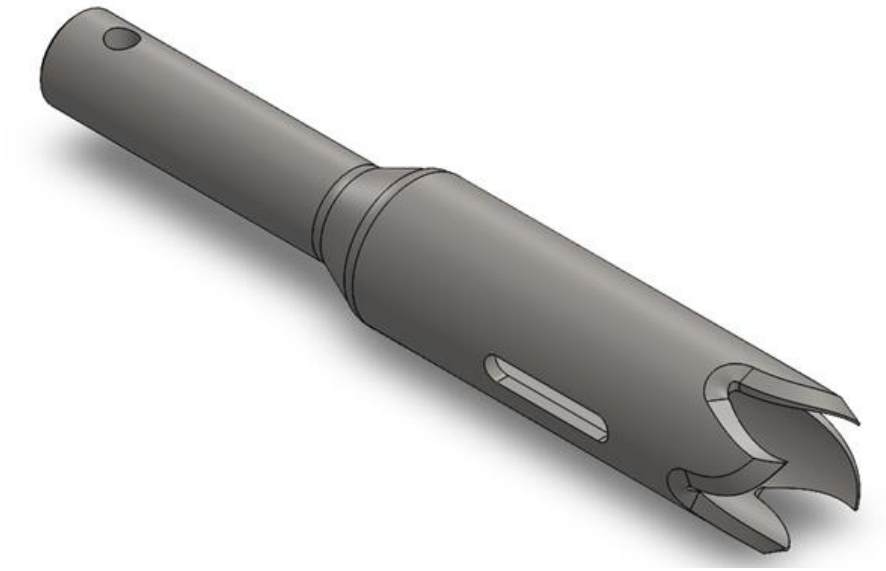


Fig. 4.4 Model of embryo plug scooping tool tip

The material and volumetric properties of SS 304 were presented in table 4.9 and 4.10.

Table 4. 9 Material properties of tool

Properties		
Name	:	AISI 304
Model type	:	Linear Elastic Isotropic
Default failure criterion	:	Unknown
Yield strength	:	2.06807×10^8 N m^{-2}
Tensile strength	:	5.17017×10^8 N m^{-2}
Elastic modulus	:	1.9×10^{11} N m^{-2}
Poisson's ratio	:	0.29
Mass density	:	8,000 kg m^{-3}
Shear modulus	:	7.5×10^{10} N m^{-2}
Thermal expansion coefficient	:	1.8×10^5 K^{-1}

Table 4.10 Volumetric properties of the tool

Property		
Mass	:	0.0668792 kg
Volume	:	8.35993×10^{6} m³
Density	:	7,999.97 kg m^{-3}
Weight	:	0.655416 N

4.4.1 Loads and Fixtures

Fixtures are defined as fixed restraints. Each restraint can contain multiple faces. The restrained faces were constrained in all directions. Fixtures are faced where resultant forces of body get concentrated s shown in table 4.11,4.12,4.13.

Table. 4.11 Fixtures

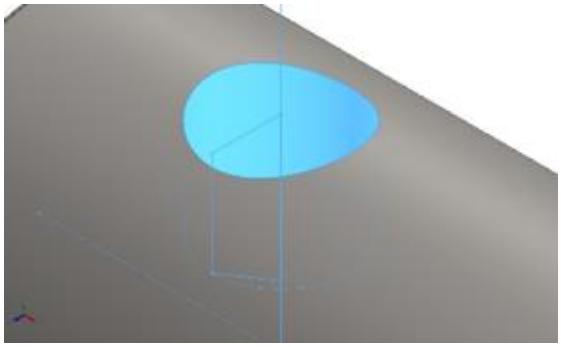
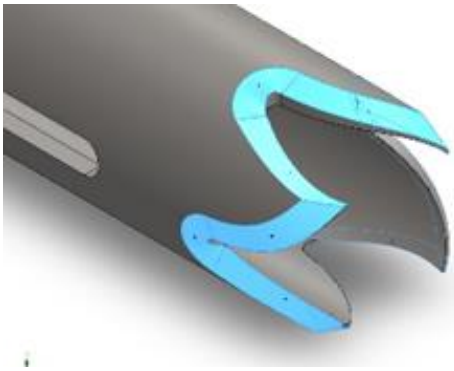
Fixture name	Fixture image	Fixture details
Fixed-1		Entities: 1 face Type: Fixed geometry

Table 4.12 Loads

Load name	Load image	Load details
Force - 1		Entities : 12 faces Type : Apply normal forces Valu: : 38 N

Torque - 1		Entities : 4 faces Type : Apply torque Value : 1.5 N·m

Table 4.13 Mesh details

Mesh type	: Solid mesh
Mesher used	: Blended curvature-based mesh
Maximum element size	: 4.06916 mm
Minimum element size	: 0.296277 mm
Mesh quality	: High
Total nodes	: 8871
Total elements	: 4388
Maximum aspect ratio	: 902.72
% of elements with aspect ratio <3	: 93.6
% of elements with aspect ratio >10	: 1.05
% of distorted elements	: 0

4.4.2 Resultant forces

Resultant force is the effective force of reaction forces along 3 mutual axes, acting on the body. Based on computer simulation through solid works, resultant force was obtained was 7.52619 N as shown in table 4.14.

Table 4.14 Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire model	N	-7.52619	-0.00384808	0.00356102	7.52619

4.4.3 Stress on locking screw

Stress is the intensity of induced internal forces (force per unit area) due to external applied forces. Von Mises stress is a value used to determine if a given material will yield or fracture. It is mostly used for ductile materials, such as metals. The stress calculated for the locking screw on which the resultant of all the load and torque acted upon, and was presented in table 4.15.

Table. 4.15 Von Mises stress

Name	Type	Min	Max
Stress 1	VON: Von Mises Stress	9.600×10^4 N m^{-2} Node: 864	8.465×10^7 N m^{-2} Node: 7145

Based on the simulation model and force analysis (Table 4.15) it was observed that, the maximum stress induced was 8.465×10^7 N m^{-2}. Therefore, the designed dimensions, cross section and selected material of construction were safe for the actual operating conditions.

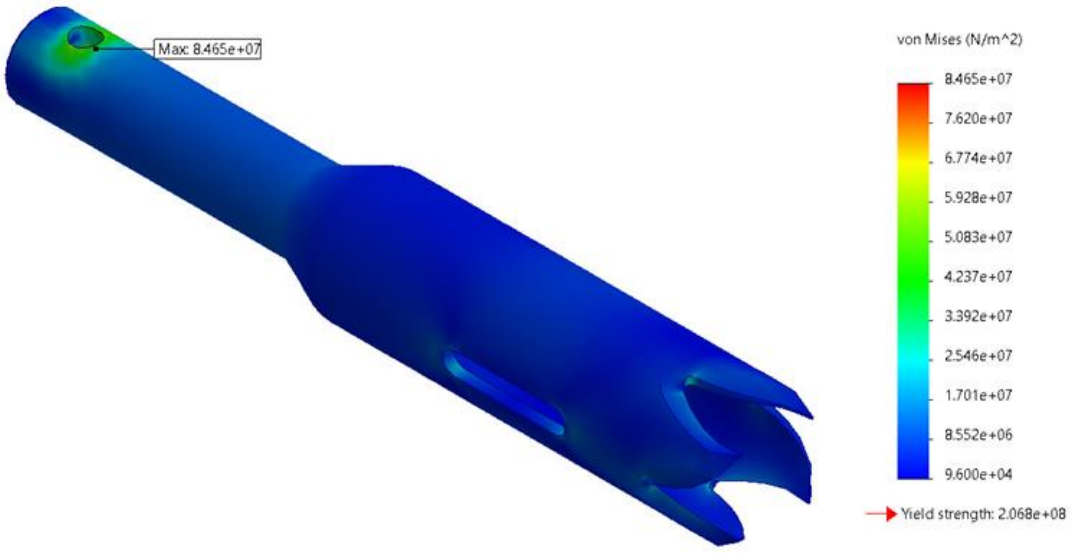


Fig. 4.5 von Mises Stress distribution under load

From fig 4.5 it was observed that, maximum von Mises stress obtained as 8.465×10^7 N m^{-2}. and the yield strength of ss 304 is 2.068×10^8 N m^{-2}. From these values the factor of safety was calculated as 2.5. Hence the design is safe.

4.4.3.1 Design of locking screw

Diameter of thread = 4 mm

Nominal diameter of M_4 SS screw = 3.24 mm

Tensile strength of SS 304 screw = 515 MPa

= 515 N/mm^2

Then, Shear strength of SS 304 screw = 0.5 × Tensile strength

= 0.5 × 515 N/mm^2

= 257.5 N/mm^2

Maximum stress at the point of locking screw = 8.465×10^7 N m^{-2}

= 84.65 N/mm^2

So that, the locking screw of material SS 304 and nominal diameter 3.24 mm (M_4 screw) can withstand the maximum stress developed on the tool (8.465×10^7 N m^{-2}). Hence the design of locking screw is safe.

4.4.4 Resultant displacement

The resultant displacement refers to the change in location of a point expressed as distance and direction of the vector measured along a straight line from the initial to the final position.

Table. 4.16 Resultant displacement

Name	Type	Min	Max
Displacement	Resultant displacement	0 Node: 83	1.32×10^{-2} mm Node: 74

The simulation study revealed that the maximum displacement at the tool tip was 1.32×10^{-2} mm as detailed in table 4.16.

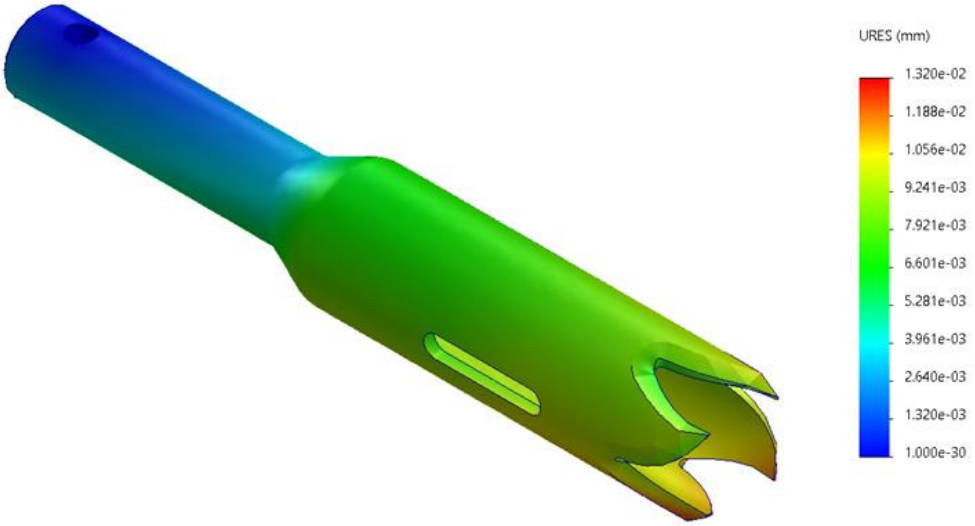


Fig. 4.6 Displacement under load

4.4.5 Equivalent strain

A scalar called the equivalent strain, is a non-dimensional quantity often used to describe the state of strain in solids. The computer-aided simulation in solid works determined the maximum equivalent strain to be approximately 2.331×10^{-4} which was infinitesimally small compared to the strength characteristics of the SS 304.

Table. 4.17 Equivalent Strain

Name	Type	Min	Max
Strain	Equivalent Strain	1.437×10^{-7} Element: 4383	2.331×10^{-4} Element: 2025

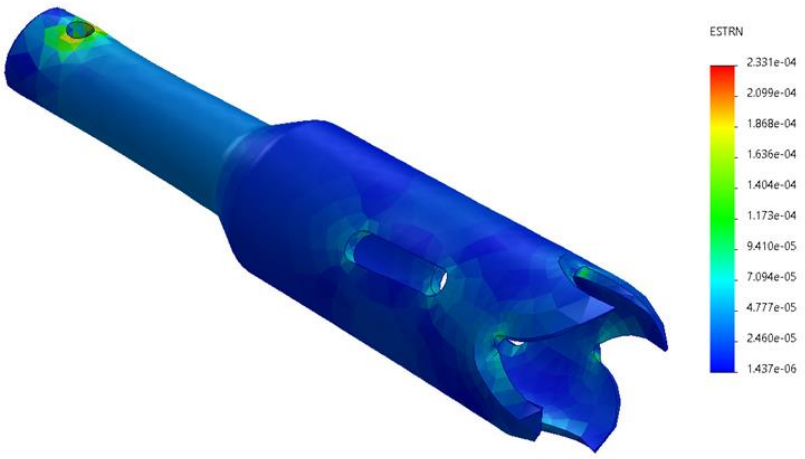


Fig. 4.7 Equivalent strain distribution under load

4.5 PHYSIOLOGICAL STERSS ASSESSMENT

Heart rate (HR) in beats per minute (bpm) was monitored during the operation of the tool in the lab using portable heart rate sensor. The assessment was carried out using 5 different hand tool and one motorized tool. Two subjects operated each tool for 10 minutes. In between the operation the subjects were allowed to take a rest for about 10 minutes before starting new tool for operation. Result obtained were presented in table 4.18.

Table 4. 18 Energy consumption for two subjects

Subject	Tool name	Resting heart rate (bpm)	Average heart rate (bpm)	Maximum heart rate (bpm)	ΔH (bpm)	Oxygen consumption (L min^{-1})	Energy expenditure (kJ min^{-1})
Subject 1	Round tip	75	89	109	34	0.726	15.17
	Serrated tip	75	82	105	30	0.67	14.003
	Saw-tooth tip	75	85	103	28	0.642	13.41
	Saw-tooth with gap	75	87	109	34	0.726	15.17
	Curved tip	75	86	102	27	0.628	13.12
	Curved tip with motor	75	81	101	26	0.614	12.83
Subject 2	Round tip	90	106	127	21	0.807	16.86
	Serrated tip	90	92	126	34	0.796	16.63
	Saw-tooth tip	90	95	123	28	0.763	15.94

Saw-tooth with gap	90	107	124	17	0.774	16.17
Curved tip	90	102	120	18	0.730	15.25
Curved tip with motor	90	91	106	15	0.576	12.03

The physiological assessment indicates a significant reduction in energy expenditure when using a motorized tool for the extraction of a coconut embryo (fig 4.8). This reduction was attributed to the mechanical assistance provided by the motor, which facilitates easier penetration and cutting of the coconut. Unlike manual methods, where the operator must exert substantial physical effort to cut through the coconut endosperm, the motorized tool efficiently performs these tasks with minimal human input.

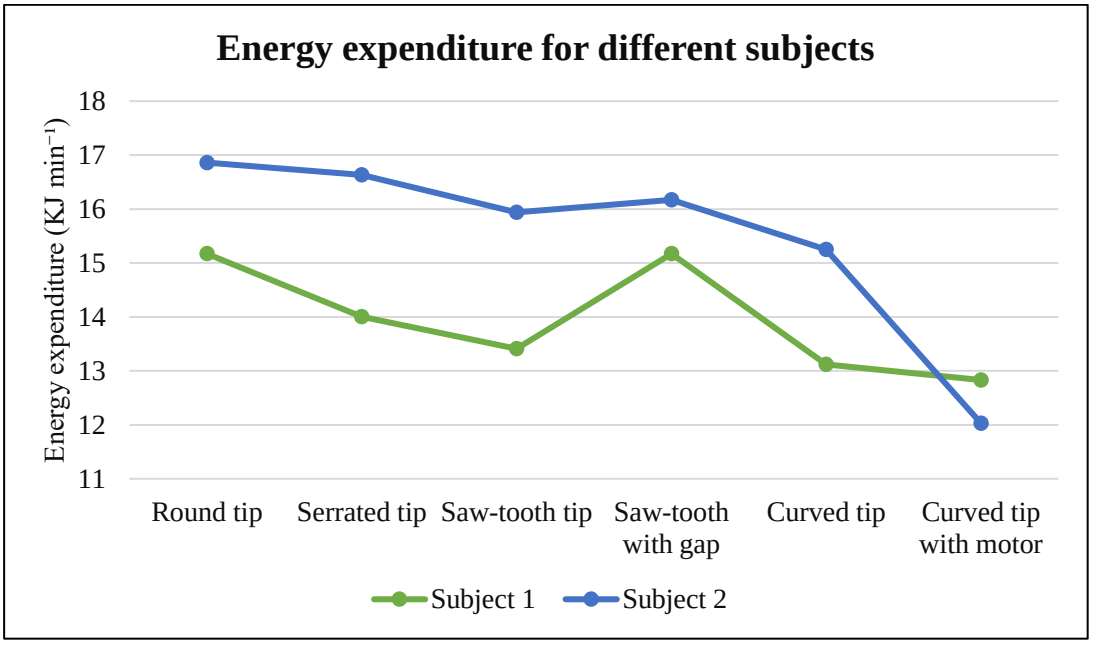
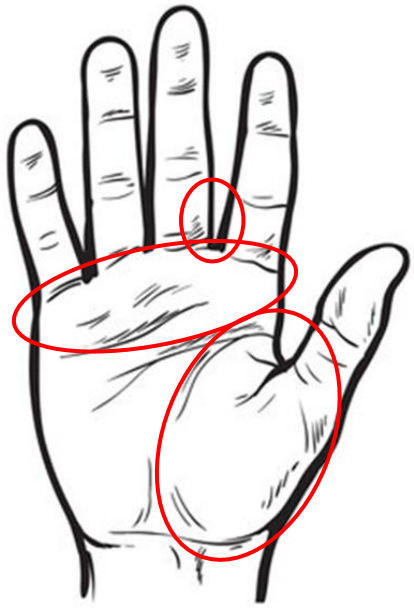
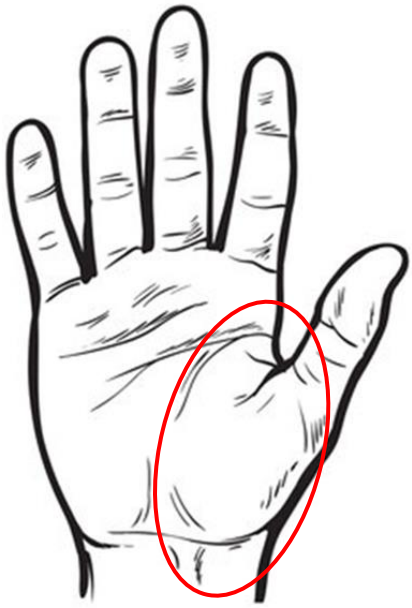


Fig.4.8 Energy expenditure graph for different tools for different subjects

4.5.1 Discomfort analysis

The subjects were asked to perform specific tasks with each of the five hand tools and the motorized tool. Observations and subjective feedback were collected to evaluate the ergonomic impact and user comfort associated with each tool.

Table 4.19. Discomfort comparison on palm for hand tool and motorized tool

Hand Tools Operation	Motorized Tool Operation
	
i. Both subjects reported experiencing pain localized to the palmar region, particularly beneath the fingers and adjacent to the thumb. Also, in between middle finger and point finger where the tool handle was placed. ii. The discomfort was noted consistently across all five hand tools used during the tasks. iii. This pain suggests a potential strain or pressure exerted on the palmar surfaces and the muscles and tendons associated with the thumb and fingers.	i. When operating the motorized tool, both subjects reported a significant reduction in physical discomfort. ii. Pain in palm near to thumb was experienced, while operating using this tool. iii. The motorized tool was found to be easier to handle and operate, leading to no reported issues of pain or strain. iv. This ease of operation may be attributed to the reduced manual effort required, thereby decreasing the physical load on the palmar region and thumb.

The consistent pain experienced with hand tools indicates a need for ergonomic improvements in their design to mitigate the strain on the palm and thumb. The motorized tool, however, provided a more comfortable user experience, highlighting the benefits of mechanical assistance in reducing physical stress.

SUMMARY AND CONCLUSIONS

CHAPTER V
SUMMARY AND CONCLUSION

Coconuts are an incredibly versatile and important resource in many parts of the world, especially in tropical regions. The propagation methods for coconut is one of the most challenging, while considering conventional coconut propagation methods. However, nut productions can be improved by different types of embryo cultures, like tissue culture, cryopreservation etc. The key factor challenging the extraction of coconut embryos for these propagation methods are the unavailability of efficient and effective tools.

To address this issue, a research project was undertaken to design and develop a motorized coconut embryo plug scooping tool. The objectives of the study included to study the morphological characteristics of coconut for the systematic design of coconut embryo scooping tool, to fabricate coconut embryo scooping tool as per the design, to evaluate different tool geometries for design optimization and to motorize the tool for operational easiness. The unit consisted of a curved tool tip, an embryo expelling unit, a torque providing motor of 1.5 kg cm and an adapter of 12V. The overall length of the tool is about 20 cm. The development cost of coconut embryo plug scooping tool was approximately Rs. 2000/-.

For the development of coconut embryo plug scooping tool, a total of five tool tips were designed and made viz, round tool tip, serrated tool tip, saw-tooth tool tip, saw-tooth tooltip with gap and curved tool tip. For optimizing a tool tip, a lab test was conducted. By considering factors such as easiness of cut, damage of embryo, shape of cut, scooping efficiency, time of operation and field capacity for each tool, curved tool tip was performed in a better way. The curved blade demonstrated superior performance in terms of ease of operation and reduced extraction time, making it a practical choice for large-scale propagation efforts.

As the tool is used mainly in biotechnology labs for coconut, the material of construction was selected by considering the food grade i.e., Stainless Steel (SS) 304. For the determination of various forces acting on the tool, piercing test and torque test were done. Force analysis was done in order to find the stress, displacement and strain acting on the tool.

For the assessment of ergonomic aspects and physiological cost associated with using coconut embryo plug scooping tool heart rate measurement was conducted for two subjects. The analysis concluded that all the tools except motorized ones lead to increased heart rate, oxygen consumption rate and energy expenditure rate resulting in operational fatigue.

In conclusion, the motorized coconut embryo plug scooping tool represents a significant technological improvement in extracting the explant for coconut propagation. By addressing the limitations of existing methods and incorporating detailed force and design analyses, this tool enhances the efficiency and success rate of coconut embryo extraction.

The implications are: technological shift in harvesting explant for coconut in-vitro propagation; faster, efficient and user-friendly tool (manual/motorized) and economical solution for research and industrial purpose.

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COCONUT EMBRYO PLUG SCOOPING TOOL

by

HARSHA P (2020-02-004)

NITHYA ROBERT (2020-02-005)

FATHIMA MARIYAM SA ADIYA (2020-02-011)

DILKHUSH GIRI (2020-02-051)

ABSTRACT

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY, TAVANUR – 679 573,

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ABSTRACT

A specialized coconut embryo plug scooping tool was developed to effectively extract the coconut endosperm along with the coconut embryo. The equipment comprises several key components like a scooping tool tip designed with a curved blade, an embryo expelling unit, a motor providing 1.5 kg cm of torque, and a 12 V adapter to power the motor.

To achieve optimal performance, comprehensive laboratory studies were conducted, examining five different tool tip designs. Among the tested designs, the curved tool tip emerged as the most effective, offering superior cutting efficiency while minimizing damage to the delicate embryo. The operational efficiency and user-friendliness of the tool were significantly enhanced by the incorporation of the motor, which works in conjunction with the curved tool tip. This motorization not only improves the precision and ease of the cutting process but also reduces the manual effort required, making the tool more practical for large-scale use. The integration of these components ensures that the tool is both effective in its primary function of embryo extraction and convenient for operators, addressing a critical need in the propagation of coconuts through advanced techniques such as tissue culture and cryopreservation.

The development of a motorized coconut embryo plug scooping tool designed to enhance efficiency and success rates in coconut propagation. By addressing the limitations of existing methods through comprehensive force and design analyses, the tool significantly reduces operational fatigue compared to non-motorized alternatives.

The motorized coconut embryo plug scooping tool represents a significant technological improvement in extracting the explant for coconut propagation. By addressing the limitations of existing methods and incorporating detailed force and design analyses, this tool enhances the efficiency and success rate of coconut embryo extraction.