DEVELOPMENT OF CASHEW FRUIT COLLECTOR AND CASHEW APPLE AND NUT SEPARATOR

by

KAVYA ANIL (2021-02-016)

SHIFNA SHERIN CT (2021-02-022)

ABHIRAMI KRISHNA (2021-02-024)

DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND FOOD TECHNOLOGY TAVANUR – 679573

MALAPPURAM, KERALA, INDIA

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PROJECT REPORT

Submitted in partial fulfillment of the requirement for the degree of

BACHELOR OF TECHNOLOGY
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DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND FOOD TECHNOLOGY TAVANUR – 679573

MALAPPURAM, KERALA, INDIA

2025

DECLARATION

We hereby declare that this project entitled "**DEVELOPMENT OF CASHEW FRUIT COLLECTOR AND CASHEW APPLE AND NUT SEPARATOR**" 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.

KAVYA ANIL (2021-02-016)

SHIFNA SHERIN C T (2021-02-022)

ABHIRAMI KRISHNA (2021-02-024)

Place: Tavanur

Date:

CERTIFICATE

Certified that the project entitled **"DEVELOPMENT OF CASHEW FRUIT COLLECTOR AND CASHEW APPLE AND NUT SEPARATOR"** is a record of project work done jointly by Kavya Anil (2021-02-016), Shifna Sherin C T (2021-02-022), Abhirami Krishna (2021-02-024) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship, or associateship to them.

Place: Tavanur

Date:

Guide: Dr. Dhalin D.
Professor
Dept. of FMPE
KCAEFT Tavanur

Co-guide: Dr. Edwin Benjamin
Assistant Professor (C)
Dept. of FMPE

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Shifna Sherin C T **Kavya Anil** **Abhirami Krishna**

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SYMBOLS AND ABBERVIATIONS

Sl No.	Abbreviation or Notation	Description
1.	viz.	Namely
2.	et al	And others
3.	%	Per cent
4.	i.e.	That is
5.	mm	Millimetre
6.	cm	Centimetre
7.	km	Kilometre
8.	FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
9.	mg	Milligram
10.	GAE	Gallic Acid Equivalents
11.	/	per
12.	Fig.	Figure
13.	m	Metre
14.	N	newton
15.	h	hour
16.	m^3	cubic metre
17.	g	gram
18.	kg	kilogram
19.	rpm	revolutions per minute
20.	SS	Stainless steel
21.	V	volt
22.	W	watt
23.	AC	Alternating current
24.	DC	Direct current
25.	VA	Volt ampere

INTRODUCTION

CHAPTER I

INTRODUCTION

The cashew apple, or *Anacardium occidentale L.*, is an evergreen tree that belongs to the Anacardiaceae family and is native to some parts of Brazil. Due to its popularity and strong nutritional and nutraceutical properties, it has greatly expanded in South American and Asian countries. Although, the fruit of cashew apple tree is referred as "pseudo-fruit" and has a nut attached. Typically, fruiting and harvesting occur between December and March, however occasionally they continue into late April (Pereira *et al.*, 2011). Cashew apples are elongated, round or pear-shaped fibrous fruits. The fully developed cashew apple is firm and juicy (Marc *et al.*, 2012). It is a rich source of total polyphenols, volatile components, vitamin C, minerals, flavanols, and amino acids (Queiroz *et al.*, 2011). The raw cashew nut is kidney shaped with 3.5 mm thick soft leathery outer skin (epi carp) and thin hard inner skin (endocarp) (Ohler., 1979).

Cashew is one of the most important commercial crops in India, 0.43 million ton of raw nuts being produced from an area of 6590 km^2 (Balasubramanian., 1997). In 3650 cashew processing mills across the country, the country processed about 1.14 million tonnes of cashew. From 170 in 1959 to over 3500 in 2008, the number of cashew processing mills has increased dramatically (Saroj and Balasubramanian., 2013). Around 0.5 million individuals are employed in the business, with nearly all of them being women. In cashew processing, 46% of the work is carried out by large, registered, and regulated units (organised sector), while the remaining 54% is handled by small, informal, and often unregistered units (unorganised sector).The annual demand for cashew processing in India is 1.5 million tonnes, with only half of it being met by current production (Walavalkar., 2022).

In 2023, India produced approximately 782,000 tonnes of in-shell cashew nuts from about 1.195 million hectares of land. According to FAOSTAT (2023), this accounts for 19.87% of global cashew production, utilizing 30.4% of the world's cashew cultivation area. The states that give the most to the nation include Tamil Nadu (9.8%), Kerala (10.76%), Orissa (13.7%), Maharashtra (32.3%), and Andhra Pradesh (16.15%), indicating that the crop is increasing the fastest in the peninsular region. India is the biggest cashew importer in the world, particularly of African goods (Walavalkar., 2022). According to the first cashew description provided by Cristovao da Coasta, Cochin was a cashew dispersal hub for India and maybe South-East Asia. Cashews were first cultivated in India mainly as a soil conservation crop, but as their commercial value became apparent, they became one of the most significant plantation crops in the horticultural industry (Saroj and Balasubramanian., 2013).

Despite being the world's greatest producer, India still has a long way to go in terms of popularizing cashew apple products in the global commercial market. Its extreme perishability is one of the main causes of its reduced production and commercialization. It remains fresh for only one to two days after harvest, after which it begins to deteriorate due to its quick senescing metabolism. Therefore, increasing the availability of appropriate facilities for storage, packaging, and handling systems is the first key concern for promoting large-scale production and wider adoption. As the moisture content of the fruit is normally very high (above 80% wet basis), keeping the fruit safe against the microbial spoilage is also a major challenge (Attri and Singh., 1997).

Current mechanized systems available for similar crops are either not adaptable due to the irregular size, shape, and dispersion pattern of cashew fruits on the ground, or they lack effective mechanisms to separate the nut from the apple efficiently during collection. Additionally, there is limited literature and field-tested prototypes specifically tailored to the unique post-harvest challenges of cashew collection. Therefore, there is a significant research gap in the development of an integrated, low-cost, and efficient unit that can mechanically collect scattered cashew fruits from the ground while also separating the nuts from the apples in a single operation. Addressing this gap would not only reduce dependency on manual labour but also improve the speed, quality, and cost-efficiency of post-harvest cashew processing. The development of such a system is essential to support small and medium-scale farmers in enhancing productivity and sustainability in cashew farming operations (Pai et al.,2019).

The development of a cashew fruit collector and nut separator is both timely and essential. It addresses key challenges in manual harvesting, including labour dependency, physical strain, inefficiency, and post-harvest losses. By integrating collection and separation processes into a single mechanized unit, such a system can significantly enhance productivity, ensure better quality produce, and promote hygienic handling. Moreover, it aligns with the broader goals of sustainable agricultural mechanization, particularly in cashew-growing regions where small and medium-scale farmers often lack access to efficient post-harvest tools. This research aims to design and evaluate a practical, cost-effective solution to bridge this gap and support improved cashew production systems.

OBJECTIVES

1. To study the physical and structural characteristics of cashew apples and nuts for the systematic design of the collection and separation unit.
2. Design and development of a prototype for efficient collection of cashew apples and nuts from the ground.
3. To develop a mechanism for separating cashew nuts from the fruits with minimal damage and manual effort.
4. To evaluate the performance of the developed equipment for design validation and optimization.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

The importance of cashew fruit and the implements used for its collecting and separation is reviewed and presented in this chapter under major subsections viz. physical and engineering properties, harvesting and picking methods, mechanical harvesting and picking methods, separation of cashew nut from cashew apple

2.1 PHYSICAL AND ENGINEERING PROPERTIES

Singh *et al*. (2019) conducted a comprehensive study to characterize its physical, thermal, and textural properties, which are crucial for developing suitable postharvest handling and processing technologies. The fruit is oblate-ellipsoid in shape, with a sphericity of 0.85, indicating its moderately rounded form. It exhibits average dimensions of 50.34 mm in length, 42.78 mm in width, and 36.08 mm in thickness. Its surface area was reported to be approximately 5,717.96 mm^2. With a high moisture content of 85.62% (wet basis), the cashew apple is extremely soft and perishable, which limits its shelf life to about 1–2 days after harvest. The fruit is rich in bioactive compounds, including total sugars (10.573%), ascorbic acid (218.933 mg/100 g), and phenolic compounds (365.303 mg/100 g GAE). Despite its nutritional value, it is underutilized primarily due to its astringent taste, caused by tannins, and the lack of appropriate processing technologies. These characteristics underscore the need for further research and innovation in cashew apple processing to enhance its commercial viability.

Manjunatha et al. (2023) reported that cashew apple is a soft, fibrous pseudo-fruit with considerable variation in its physical characteristics across varieties. The fruit exhibits a conical-obovate shape with sphericity ranging from 0.76 to 0.89, and dimensions such as length, width, and thickness varying from 54.15–60.74 mm, 40.62–50.77 mm, and 35.63–44.81 mm, respectively. Its high moisture content contributes to a short shelf life, making it highly perishable. The study emphasized that understanding physical traits such as surface area, bulk density, and porosity is essential for designing effective postharvest handling and separation equipment.

Sethi et al. (2015) evaluated 60 cashew hybrids along with their parents and checks, and reported significant variation in nut and apple traits. Apple weight ranged from 30.69 g to 89.0 g, and apple length from 3.58 cm to 7.84 cm across hybrids. The study also highlighted that apple to nut ratio (ANR) and total soluble solids (TSS) were highest in hybrids where VTH-711/4 was used as the male parent. These findings suggest that selection based on apple traits like weight, size, and ANR can be valuable in hybrid development programs targeting processing suitability.

Isa and Aderotoye (2017) investigated the effect of moisture content on the physical and aerodynamic properties of cashew nuts, focusing on dimensions, sphericity, density, porosity, and terminal velocity. Their study revealed that increasing moisture content from 4.0% to 10.8% (wet basis) led to significant changes in these properties, such as increased length, width, thickness, and terminal velocity, while sphericity and porosity exhibited nonlinear trends. The findings highlighted the importance of moisture content in designing processing equipment for cashew nuts, particularly for operations like sorting, grading, and shelling. The authors emphasized that higher moisture levels improved shelling efficiency, suggesting optimal processing conditions to enhance yield and quality. This research provides valuable data for engineers and agro-processors aiming to optimize cashew nut processing systems.

Anand et al. (2015) conducted a comprehensive study to evaluate the physico-chemical characteristics of ten cashew (Anacardium occidentale L.) varieties cultivated in Odisha, India. The research assessed physical parameters such as fruit weight, girth, and juice content, as well as chemical properties including ascorbic acid, total soluble solids (TSS), pH, sugars, and acidity. Significant variability was observed among the varieties, with Jagannath displaying the highest fruit weight (75.44 g) and juice content, while BPP-8 had the highest ascorbic acid content (275.37 mg/100g). Screw-type juice extraction was found to be more effective than grinder-based methods. Among the varieties, Jagannath and Balabhadra emerged as the most promising for commercial juice production due to their favourable combination of high yield, quality juice parameters, and nut characteristics.

2.2 MANUAL HARVESTING AND PICKING METHODS

Dendena and Corsi (2014) concluded that cashew plants typically flower for 2 to 3 months, and the fruits mature about two months after blooming. When fully ripe, the entire fruit falls to the ground, and harvesting generally involves manually collecting the nuts from the ground- a labour-intensive process often carried out by women and children. However, for fresh consumption and juice production, where high-quality apples are required, some farmers prefer harvesting the apples directly from the plant to prevent pilferage and bursting. In such cases, a small basket or sack attached to a ring on a long stick is commonly used. To preserve quality, the nut is separated from the apple and dried shortly after harvesting, while the apple is typically processed within 24 hours. Traditionally, the nuts are sun-dried for 2 to 3 days, reducing their moisture content from around 25% to 7-8% before further processing.

According to the Gesellschaft für Internationale Zusammenarbeit (GIZ) (2012), effective cashew nut harvesting practices are crucial for maintaining nut quality and minimizing post-harvest losses in Ghana. The recommended approach involves collecting cashew fruits only after they have naturally fallen to the ground, signifying full maturity. This practice typically begins in late January, with peak harvesting occurring between February and March. GIZ advises against plucking fruits directly from the tree, as this can lead to immature nuts and reduced quality. Regional climatic differences also influence harvesting frequency; while a three-day interval is sufficient in southern Ghana, the hotter northern regions require daily collection to prevent heat-induced deterioration. Pre-harvest weeding beneath cashew trees is recommended to facilitate efficient fruit gathering. Once collected, apples should be carefully detached from the nuts using a nylon thread or sharp knife to avoid damage. The nuts are then dried on shaded surfaces such as tarpaulins or concrete for three to four days, with regular turning to ensure uniform drying. These best practices significantly contribute to preserving nut quality and enhancing market value.

Mohan Ray and Rajaram (1999) conducted a comprehensive study on cashew harvesting and processing techniques at the University of Agricultural Sciences, GKVK, Bangalore. Their research emphasized the importance of collecting cashew nuts after natural fruit drop to ensure full maturity and optimal quality. They observed that premature harvesting, such as shaking branches or picking fruits directly from the tree, often led to immature nuts with lower kernel quality and increased post-harvest losses. The study also highlighted the significance of timely collection, recommending that fallen nuts be gathered daily during the peak harvest season to prevent spoilage and pest infestation. Furthermore, the researchers explored improved methods for detaching nuts from the cashew apple, suggesting the use of specific tools to minimize damage. Their findings contributed to developing best practices aimed at enhancing nut quality, reducing labour inefficiencies, and minimizing post-harvest losses in cashew cultivation.

2.3 MECHANICAL HARVESTING AND PICKING METHODS

Fayose (2023) presented the development and performance evaluation of a motorized cashew nut picker, addressing the challenges posed by the labour-intensive and unhygienic nature of manual nut collection. The design incorporates a rotating cylindrical drum equipped with flexible rubber fingers, which gently comb through the soil surface to dislodge and lift fallen cashew nuts. These fingers are engineered to prevent damage to the nuts during collection, thereby maintaining their quality. Once picked, the nuts are conveyed through an auger or belt conveyor mechanism into a designated collection bin, ensuring a streamlined handling process. The entire system is powered by a motor and mounted on a wheeled frame, allowing for mobility and adaptability across different terrain conditions. Fayose's mechanized solution significantly enhances operational efficiency, improves the hygienic standard of the harvested nuts, and reduces the physical strain on labourers. This development demonstrates the potential of simple mechanical innovations to transform traditional agricultural practices, especially in small- to medium-scale farming contexts where manual harvesting remains prevalent.

El-Hagarey et al. (2023) describes the development of a prototype automatic harvester designed specifically for peach fruits. The picking mechanism relies on a trunk shaking system that uses a hydraulic motor to generate controlled vibrations transmitted to the tree trunk. This vibration causes mature peach fruits to detach from their pedicels due to the inertia generated by the shaking. To minimize fruit damage during detachment and fall, the harvester incorporates a canopy-style catching system with inclined soft padding that safely directs the falling peaches into collection bins.

The vibration frequency and amplitude are optimized to ensure efficient fruit removal without harming the tree or causing immature fruit drop. This mechanized approach significantly reduces manual labour, harvest time, and fruit losses while maintaining fruit quality.

2.4 SEPARATION OF CASHEW NUT FROM CASHEW APPLE

Harish Hadimani (2020) designed an automated nut separating mechanism in their study “Design and Analysis of Nut Separator from Cashew Fruit”, aimed at addressing labour-intensive and inefficient manual methods. The separating mechanism operates in a staged process powered by DC motors and controlled by an Arduino-based controller unit. Cashew apples are fed into a hopper made of mild steel, where a rotating guiding plate ensures a controlled, one-by-one flow of the fruits. These guided fruits fall onto a stopper, and at that moment, a second motor activates a rack-and-pinion assembly connected to a tool-edge blade. This blade precisely separates the nut from the cashew apple. After separation, another motor-driven mechanism pushes the leftover apple to the side, allowing continuous operation. This mechanical design significantly reduces human effort, enhances speed, and improves the efficiency and safety of the cashew nut separation process.

Sawant *et al.,* (2025) present an innovative approach in their study titled “Design and Development of Cashew and Nut Separating Machine”, aimed at mechanizing the traditionally manual and labour-intensive process of separating cashew nuts from cashew apples. The authors developed a machine consisting of a structured assembly that includes a feeding unit (hopper), paired rollers, cutting blades, and a separation mechanism, all powered by a motorized system. As cashew apples are fed through the hopper, the rollers grip and guide the fruit towards a cutting blade, which is precisely positioned to slice the apple and detach the nut with minimal damage. Following this, a vibratory mechanism assists in further separating the nut from the remaining fruit mass. This design not only improves the efficiency of nut extraction but also minimizes the risk of nut breakage and maintains hygiene by reducing human contact. The machine’s continuous operation capability and mechanical simplicity make it a valuable tool for small to medium-scale cashew processing units, helping to reduce labour dependency, enhance productivity, and ensure consistent quality.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The harvesting of cashew fruits is crucial not only for maximizing economic returns but also for ensuring effective agricultural management of the crop. The cashew tree produces two valuable parts: the cashew nut and the cashew apple. Timely and proper harvesting ensures high-quality nuts, which are a major export commodity and a source of income for many farmers in tropical regions. Additionally, the cashew apple, though highly perishable, can be used to make juice, jam, and alcoholic beverages, adding further value. Harvesting at the right time also helps maintain tree health and supports sustainable production by preventing pest and disease buildup around fallen, decaying fruit.

3.1 PHYSICAL AND ENGINEERING PROPERTIES OF CASHEW

3.1.1 Apple Diameter

The diameter of the cashew apples was measured using a vernier calliper for accurate assessment. Fully matured and healthy cashew apples were randomly selected from each tree, and measurements were taken at the widest equatorial region of each fruit. A total of ten apples per genotype were measured to account for variability, and the mean diameter was calculated for each genotype. The measurements were recorded in millimetres. This method aligns with the standard procedure used in cashew varietal evaluation studies (Panda.,2015).

Plate. 3.1 Measuring diameter of fruit

3.1.2 Length

The length of cashew apples was measured using a vernier calliper with an accuracy of 0.01 mm. Mature and healthy cashew apples were randomly selected from each genotype, and the measurement was taken from the base (point of attachment to the nut) to the apex of the apple. A total of ten fruits per genotype were measured to account for variability, and the average fruit length was calculated and recorded in millimetres. This methodology aligns with the procedure described by Mirdha (2018) in her study on the physico-chemical parameters of cashew apples for value addition.

Plate. 3.2 Measuring length of fruit

3.1.3 Nut Diameter

The diameter of cashew nuts was measured using a digital vernier calliper with an accuracy of 0.01 mm. Mature and healthy nuts were randomly selected from each genotype, and measurements were taken across the widest equatorial region (width) of each nut. A total of ten nuts per genotype were measured to account for variability, and the average nut diameter was calculated and recorded in millimetres. This methodology aligns with the procedure described by Shetty (2020) in his study on the design and performance evaluation of a cashew nut grader.

Plate. 3.3 Measuring diameter of nut

3.1.4 Nut Length

The length of cashew nuts was measured using a digital vernier calliper with an accuracy of 0.02 mm. Mature and healthy nuts were randomly selected from each genotype, and measurements were taken along the longitudinal axis, from the base to the apex of each nut. A total of ten nuts per genotype were measured to account for variability, and the average nut length was calculated and recorded in millimetres. This methodology aligns with the procedure described by Krishnappa *et al*. (2023) in their study on the engineering properties of cashew apples and nuts.

Plate. 3.4 Measuring Length of nut

3.2 PICKING AND COLLECTING MECHANISMS

3.2.1 Manual Picking

The cashew fruits were collected from the ground rather than plucked directly from the tree. Fully matured fruits, which had naturally fallen, were identified based on their size, color, and firmness. Care was taken to ensure that only fresh, undamaged fruits were selected, avoiding those with signs of deterioration or pest infestation. The collection process was conducted early in the morning to minimize exposure to heat and maintain fruit quality. The gathered fruits were then transported to the sorting area, where defective or damaged ones were removed, ensuring that only high-quality samples proceeded for further processing. This method preserved the integrity of the cashew nuts, which was essential for industrial and culinary applications.

Plate. 3.5 Manual picking

3.2.2 Mechanical Picking

Mechanical picking of cashew fruits can be effectively achieved using a collection and separation machine designed to minimize labour and fruit damage. One such design consists of a wheeled frame equipped with a rotating drum and flexible fingers that gently lift cashew apples from the ground. The system also incorporates a mechanism for separating the apple from the nut, streamlining the harvesting and post-harvest processes (Wani et al., 2018).

Fayose *et al*. (2023) designed a motorized cashew nut picker to reduce manual labor and improve harvesting efficiency. The machine uses a rotating drum with rubber-padded spikes to pick nuts from the ground and a conveyor to transfer them into a collection bin. Powered by a petrol engine, the design is simple, ergonomic, and suitable for small-scale farmers. Field tests showed high picking efficiency and reduced physical effort.

Plate. 3.6 Mechanical Picking method

3.2.3 Ergonomics in Cashew Harvesting

Manual picking tasks involve repetitive hand movements and the need to maintain awkward postures such as bending, squatting, or sitting on the ground for extended periods. These activities place significant strain on the lower back, knees, shoulders, and neck, often resulting in musculoskeletal discomfort and physical fatigue. The lack of ergonomically designed tools or seating further increases the physical burden, making the task labour-intensive and uncomfortable. Prolonged exposure to such working conditions can lead to chronic pain and long-term health issues, highlighting the need for ergonomic improvements to reduce drudgery and enhance worker efficiency and well-being (Borah, 2015).

3.3 DESIGN AND DEVELOPMENT OF PICKER AND CONVEYOR

3.3.1 Development of Collector

3.3.1.1. Structural and functional design of collector plate

Cashew fruits are initially collected using a metal or polymeric plate positioned close to ground level and mechanically guided into a cup elevator for vertical conveying. The inclination of the collecting plate was determined based on the physical characteristics of the fruit (size, shape, weight, and bruising sensitivity), surface interaction (friction and texture), and operational requirements such as terrain and collection speed. As cashew apples are irregular in shape and do not roll easily, the design of the plate focused on efficient scooping and guided transfer rather than relying on gravitational rolling. According to recommendations by Zeebroeck (2007), an inclination angle between 30° and 45° was considered suitable to facilitate effective collection while minimizing mechanical damage. The collecting plate was fabricated using materials such as aluminium (Al), stainless steel (SS), and other suitable metal sheets, selected based on factors including durability, corrosion resistance, ease of fabrication, and compatibility with the fruit surface to minimize abrasion and bruising during transfer into the elevator cups.

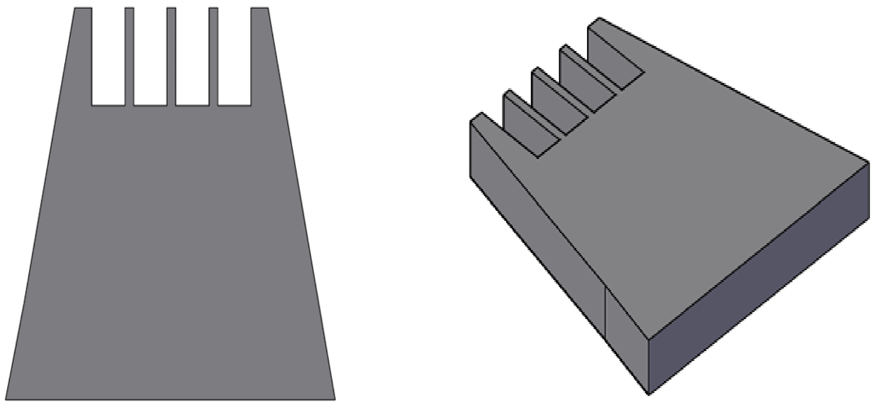

Fig. 3.1 Design of collector plate

3.3.1.2 Hinge design evaluation for collecting plate

The collecting plate, which serves as the primary interface for gathering cashew fruits from the ground, is mechanically connected to the conveyor system using hinges. This hinged connection enables the plate to maintain an inclined orientation while allowing limited movement or adjustment as required during operation. The hinges act as pivot points, effectively forming a simple lever mechanism where the plate bears the load of the fruit at its extended edge.

The total load acting at the tip of the collecting plate was estimated by considering the average weight of one or more cashew apples. A dynamic load factor of 1.5 was applied to account for additional forces due to motion, vibration, and impact during operation. The total expected load, in newtons, was calculated by multiplying the mass of the fruit by gravitational acceleration (Shingley & Mischke., 2008).

$$W = m*g*1.5 \qquad (3.1)$$

m = mass of cashew apple(s)

g = acceleration due to gravity (9.81 m/s^2)

The bending moment acting at the hinge was calculated using the formula

$$M = W \times L$$

For many hinges, bending moment in each hinge is,

$$M = (W \times L)/n \qquad (3.2)$$

M = bending moment on the hinge

L = distance from the hinge to the point where the load acts (in meters)

Manufacturer datasheets were consulted to obtain the mechanical ratings of various hinges, including their maximum load-bearing capacity and torque resistance. A safety factor of 2.5 was applied to ensure the selected hinge would operate reliably under worst-case loading conditions.

$$M \leq M_{rated} / SF$$

3.3.2 Design of Picker

The cup picker is a critical component in the cashew fruit handling system, responsible for securely receiving fruits from the collection plate and holding them during conveyor transport. The design prioritizes gentle handling, stability during motion, and compatibility with the fruit's physical properties.

3.3.2.1 Material selection

The cup pickers can be constructed using materials selected for their mechanical strength, durability, and ability to handle cashew fruits gently. Materials that can be used include polyvinyl chloride (PVC), mild steel, polyurethane (PU), and silicone rubber. PVC can be chosen for its lightweight and moldability, offering both rigid and flexible configurations. Mild steel can provide structural strength, though it may require a soft rubber or foam lining to prevent fruit damage. Silicone rubber, known for its high flexibility and food safety, can be used where the cup is required to deform to grip the fruit securely. The final design can incorporate either fully soft polymer cups or rigid structures with compliant inner linings to ensure safe and consistent fruit handling.

3.3.2.2 Geometry and Dimensions

The geometry of the cup was designed based on the average dimensions of cashew fruits observed during field trials. The internal diameter and depth were determined to accommodate the largest expected fruit dimensions, with a tolerance to support smaller fruits without excessive movement.

Model 1 – L Shaped

The cup with an L-shaped profile, as shown, is fabricated from a single sheet of material using standard bending techniques, offering a practical and cost-effective solution for fruit collection mechanisms. The design features a long vertical backplate that ensures structural rigidity and facilitates secure attachment to the conveyor mechanism. The horizontal extension serves as the fruit-holding surface, effectively supporting the load during scooping and upward transport. Its angular shape aids in preventing backward spillage and ensures that the fruits remain contained during motion on inclined or vertical paths. The L-shaped cup is particularly suitable for conditions where simplicity, ease of fabrication, and mechanical strength are essential, making it a reliable choice for evaluating collection efficiency in the cashew fruit gathering system.

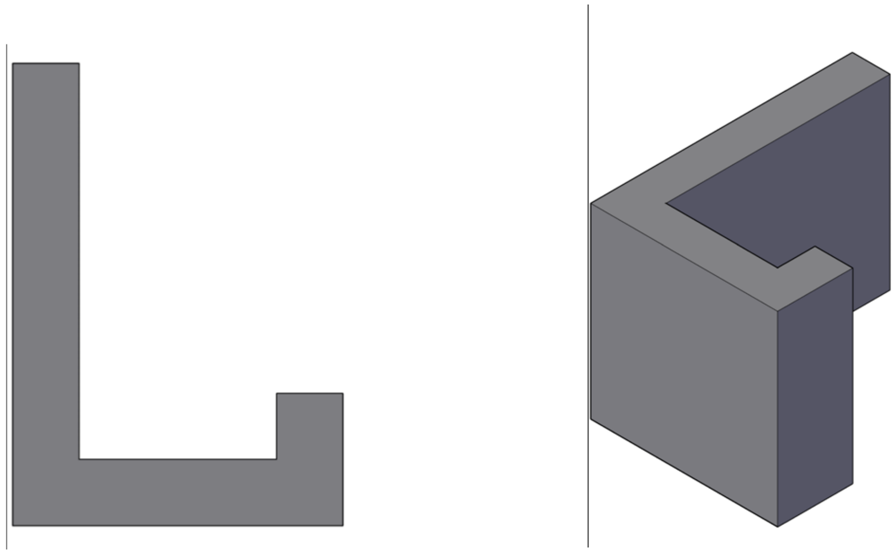

Fig. 3.2 Design of Model 1

Model 2 – J Shaped

The cup is fabricated from a single sheet of material, bent into a 'J'-shaped profile. This shape allows for effective scooping of the fruits while minimizing the risk of spillage during vertical and inclined motion. The cup features a smooth semicircular bottom with vertical sides, providing both structural stability and a sufficient holding volume. The curved section facilitates gentle handling of the fruits, reducing mechanical bruising during collection and lifting. This design was selected for evaluation due to its simplicity in fabrication using standard sheet metal bending processes, structural rigidity from the vertical backplate.

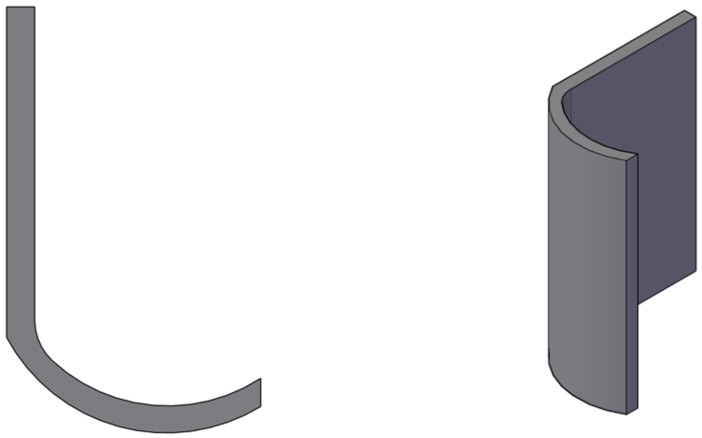

Fig. 3.3 Design of Model 2

Model 3 - J shaped with slots

The fruit picking unit is fabricated from a single, precision-bent metal piece, ensuring structural strength and operational efficiency. A curved rear section enhances lifting motion and adds rigidity, minimizing fruit damage during collection. The front features three integrated, finger-like prongs with rounded tips and contoured profiles, designed to gently scoop fruits without bruising. Strategically spaced gaps between the prongs allow soil and debris to pass through, preventing clogging and enabling smooth operation across the collector plate. This design ensures reliable performance on uneven terrain while emphasizing gentle handling, mechanical simplicity, and adaptability to varied field conditions.

Fig. 3.4 Design of Model 3

3.3.2.3 Cup Arrangement and Mounting

The cups are mounted at regular intervals along the surface of the conveyor belt using bolted or moulded attachments. Spacing between cups (s) is uniform and selected based on the average fruit size and required throughput rate. This spacing ensures that each fruit has a dedicated cavity and avoids overlapping or jamming during pickup from the plate.

3.3.3 Design of Conveyor Belt

A mechanical fruit collection system was developed to automate the retrieval and transport of cashew fruits lying on the ground. The system comprises a ground-level collection plate, a conveyor belt, and a series of picker cups attached to the belt. This section outlines the configuration and underlying mechanical principles guiding the system's design.

The fruit weight, denoted as W_f, refers to the average weight of a single cashew fruit. The number of cups per meter, represented by n, indicates how many fruit-holding cups are positioned along each meter of the conveyor system. The conveyor speed, denoted by υ and measured in meters per second (m/s), describes how quickly the conveyor moves. The conveyor length, symbolized as L, is the total horizontal distance covered by the conveyor in meters. Lastly, the cup spacing, given by s, refers to the distance between two adjacent cups on the conveyor belt and is also measured in meters.

3.3.3.1 Conveyor Belt with picker cups

Mounted on the conveyor belt are soft, compliment picker cups spaced uniformly along the belt. As fruits slide down the plate, they are guided by a drive motor and pulley, and the motion is continuous and synchronized with the collection rate.

The number of cups per unit length of the conveyor is given by:

$$n = \frac{1}{s}$$

Where, s is the cup spacing in m.

Total number of cups,

$$n_t = L \times n$$

The total load of the belt, considering average fruit weight W_f, is:

$$M = n*W_f$$

Linear speed of the belt υ,

$$\upsilon = 2\pi r*rpm/60$$

The throughput of Q_f fruits per hour is given by:

$$Q_f = (\upsilon*3600)/s \quad (3.3)$$

3.3.3.2 Drive system and Power transmission analysis

The driving force required to move the belt and the corresponding power requirement is:

$$F = M * g$$

$$P = F * \upsilon = M * g * \upsilon \quad (3.4)$$

To account for system losses, the motor power is adjusted by the efficiency factor η:

$$P_{motor} = (M * g * \upsilon) /\eta \quad (3.5)$$

3.3.4 Drive and Driven shaft design

The conveyor system operates using two primary shafts: the drive shaft, which transmits power from the motor to the belt via a pulley, and the driven shaft (or idler shaft), which supports the return side of the belt and maintains tension. Both shafts were designed based on the torque transmitted, bending loads from belt tension, and the shaft material properties.

3.3.4.1 Torque Transmission and shaft diameter calculation

The drive shaft was designed to withstand the torque required to move the loaded belt.

Torque T is calculated from the motor power and belt speed:

$$T = (P_{motor} * 60) / 2\pi N \qquad (3.6)$$

Where:

T = torque transmitted (Nm)

P_{motor} = motor power (W)

N = shaft speed (RPM)

The required shaft diameter d was estimated using the torsional shear stress formula:

$$T = (\pi/16) * \tau * d^3$$

Solving for d,

$$d = (16T/\pi\tau)^{1/3} \qquad (3.7)$$

Where:

τ = allowable shear stress of the shaft material (Pa)

A suitable factor of safety typically 1.5 to 2.5 was applied to account for fatigue and dynamic loading.

3.3.4.3 Bearing and support selection

Both shafts were supported using deep groove ball bearings housed in cast iron pillow blocks. The bearings were selected based on the shaft diameter and radial load rating. Lubrication points were provided for easy maintenance.

3.4 DEVELOPMENT OF SEPARATING UNIT

3.4.1. Overview of the Separating Mechanism

A gear-based separating unit was developed to effectively detach the cashew nut from the fruit. The mechanism utilizes mechanical pressure through a specially designed gear system that ensures controlled, balanced, and reliable operation. The complete system consists of six gears, including a main gear, one motor-driven gear, and four supporting gears. The function of this mechanism is to receive the cashew nut and press it in a controlled manner, thereby separating it from the fruit body without damaging either component.

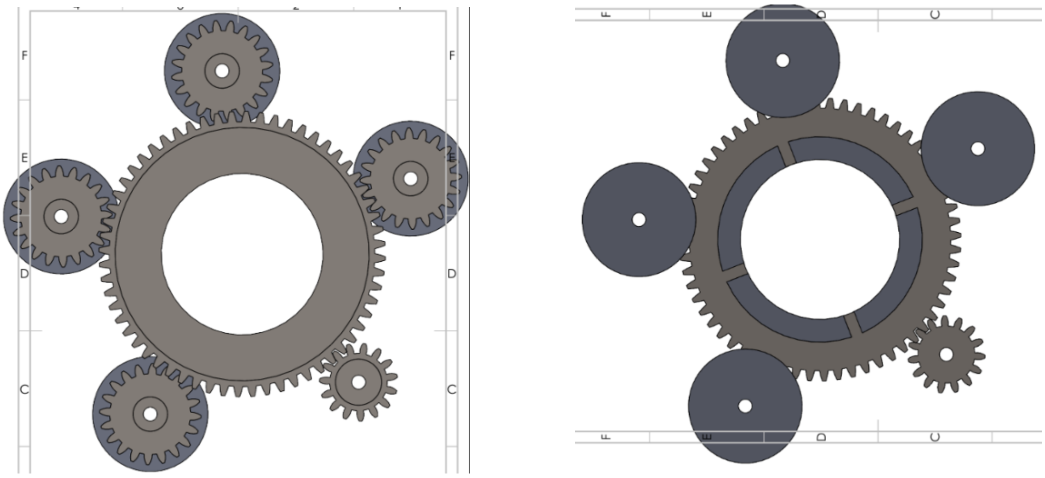

Figure. 3.5 Gear Assembly

3.4.2 Main Gear Assembly

At the core of the separating unit is the main gear, which plays a critical role in the nut detachment process. This gear is fitted with a soft rubber insert at its center. The insert contains a precisely cut groove designed to receive the cashew nut securely during operation. The groove ensures that the nut is held in position while the gear rotates, allowing consistent pressure to be applied during the separation process. The soft rubber material minimizes damage to the nut shell while enabling effective separation. The dimensions and material composition of the main gear and insert were selected based on experimental trials and fabricated using 3D printing technology for high precision.

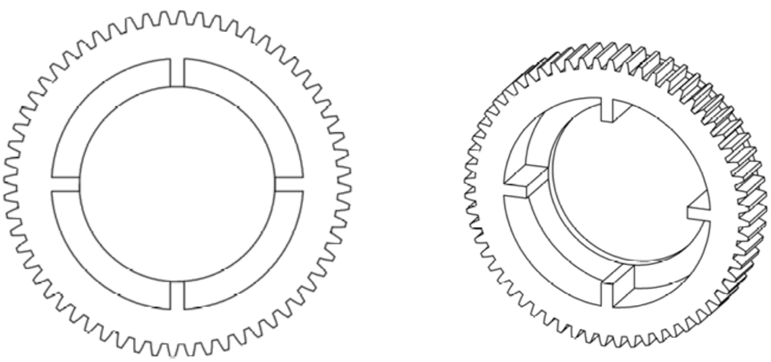

Fig. 3.6 Main Gear Assembly

3.4.3 Motor-Driven Gear

The entire system is powered by an electric motor, which provides the necessary rotational motion. The motor shaft is directly connected to one of the six gears in the assembly. This motor-driven gear is mechanically coupled to the main gear, transmitting rotational force to initiate the nut separation mechanism. The direct coupling ensures minimal power loss and consistent torque delivery. The motor specifications, such as rated power and speed, were chosen to match the load requirements of the separation task. A secure mounting arrangement connects the motor and the driven gear to avoid misalignment and operational instability.

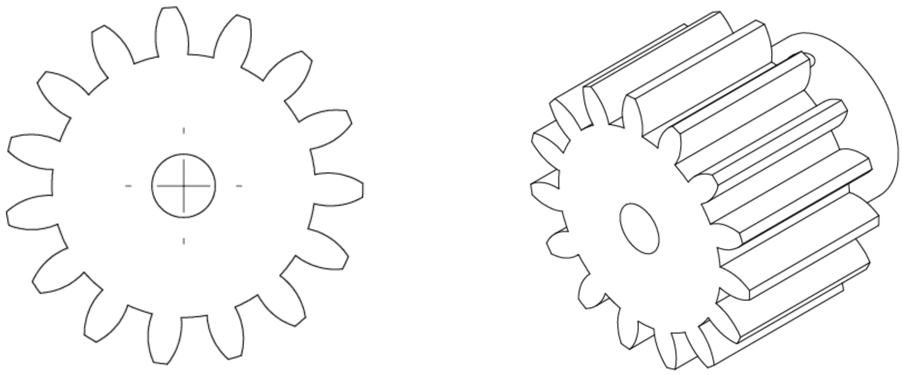

Fig. 3.7 Motor-Driven Gear

3.4.4 Supporting Gears

To ensure smooth and balanced operation, the main gear is surrounded by four supporting gears arranged symmetrically around it. These supporting gears play an essential role in stabilizing the main gear's motion and evenly distributing the operational load. Their symmetrical arrangement prevents uneven rotation, reduces stress on individual components, and ensures smooth operation. These gears do not contribute to power transmission but function primarily to provide mechanical balance and maintain gear engagement with the main gear throughout the rotation cycle.

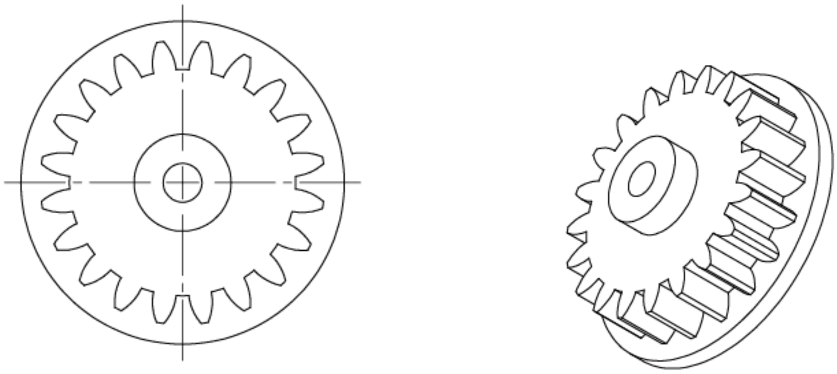

Fig. 3.8 Supporting Gears

3.4.5 Base Plate and Structural Mounting

All gears, including the main, supporting, and motor-driven gears, along with the electric motor, are mounted on a rigid base plate. This base plate serves as the foundation of the separating unit, maintaining precise alignment among the components. It minimizes operational vibrations and enhances the overall reliability of the nut-fruit separation process. The base plate also facilitates easy access for maintenance and inspection. It was fabricated with consideration for weight distribution and structural rigidity to withstand the mechanical forces generated during operation.

3.4.6 Fabrication via 3D Printing

All components of the separating unit, including the gears, inserts, and mounting structures, were fabricated using 3D printing technology. The use of 3D printing allowed for rapid prototyping, easy customization of component dimensions, and quick iteration during the design phase. It also enabled the development of complex geometries, such as the internal groove in the rubber insert, with high precision and minimal post-processing. This fabrication method significantly reduced development time and allowed for easy modifications during the testing phase to optimize the design for better performance.

The most common form of 3D printing is Fused Deposition Modelling (FDM), which uses thermoplastic filaments that are heated and extruded through a nozzle to build parts layer by layer. Two of the most widely used materials in FDM are Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) (Shahrubudin *et al*., 2019).

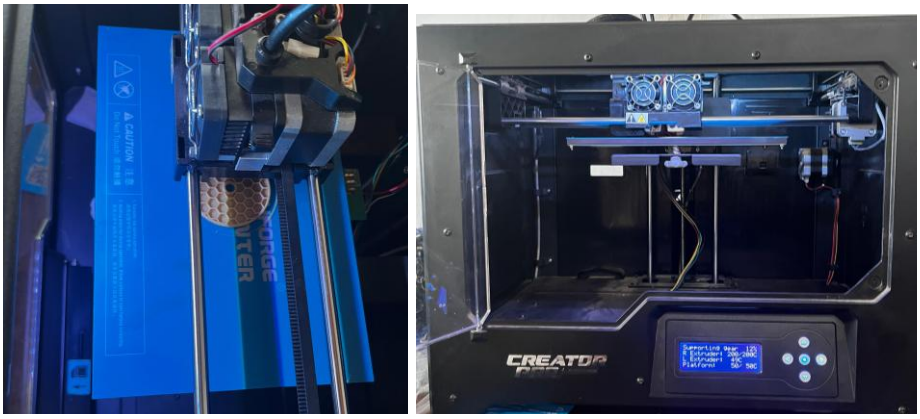

Plate. 3.7 3D Printer

RESULT AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

4.1 PHYSICAL AND ENGINEERING PROPERTIES OF CASHEW

4.1.1 Apple Diameter

The diameters of ten randomly selected cashew apples ranged from 38.9 mm to 48.6 mm. The samples had a mean diameter of 42.9 ± 3.2 mm, indicating a moderate average size with relatively low variation. This level of uniformity is beneficial for the design and calibration of harvesting and processing equipment, such as the proposed conveyor belt and picker system.

4.1.2 Length

The lengths of ten cashew apple samples ranged from 79.6 mm to 106.4 mm, with a mean length of 93.9 ± 7.9 mm. This reflects a moderate level of variability, which is important to consider in the design of handling and processing systems, as fruit length influences how the cashew apples interact with components such as conveyors, guides, and pickers.

4.1.3 Nut Diameter

The nut diameters of ten cashew samples ranged from 20.9 mm to 30.1 mm, with a mean diameter of 23.5 ± 2.9 mm. This indicates a relatively consistent size among the samples, which is advantageous for the design of nut handling mechanisms in post-harvest processing equipment.

4.1.4 Nut Length

The nut lengths of ten cashew samples ranged from 31.1 mm to 34.6 mm, with a mean length of 32.6 ± 1.02 mm. The low standard deviation reflects high uniformity in nut length, which is beneficial for the design of sizing and grading systems in processing operations.

4.2 PICKING AND COLLECTING MECHANISMS

4.2.1 Manual Picking

Bending and hand-picking cashew fruits from the ground cause physical strain, especially on the lower back and knees. Repetitive stooping leads to musculoskeletal pain and long-term posture issues. Workers often experience fatigue, reducing efficiency and increasing injury risk. Joint stress from squatting can aggravate conditions like arthritis. Uneven ground also raises the chance of slips and falls. These issues highlight the need for ergonomic and mechanized harvesting solutions.

4.2.2 Mechanical Picking

The mechanical picking approach implemented in this study demonstrated significant improvements in harvesting efficiency and reduced physical effort compared to manual collection. The system effectively lifted cashew apples from the ground using flexible components, minimizing damage to the fruits while maintaining a steady picking rate. Field observations confirmed that the mechanism reduced the need for bending and squatting, thereby addressing ergonomic concerns highlighted in manual methods. The separation mechanism also successfully detached the nut from the apple, streamlining the post-harvest process. These outcomes align with the findings of Wani *et al*. (2018) and Fayose *et al*. (2023), confirming the practicality of mechanized solutions in small-scale farming contexts.

4.2.3 Ergonomics

The adoption of a mechanical picking system significantly addressed the ergonomic challenges associated with manual cashew harvesting. Operators no longer needed to maintain prolonged bending or squatting postures, thereby reducing musculoskeletal strain on the lower back, knees, and shoulders. Users reported less physical fatigue and discomfort, validating the ergonomic advantage of mechanization. Compared to traditional hand picking, the system provided a more upright and natural working posture, which improved overall user comfort. These findings support Borah (2015), emphasizing that reducing physical stress can enhance both efficiency and worker well-being in agricultural tasks.

4.3 DESIGN AND DEVELOPMENT OF PICKER AND CONVEYOR

4.3.1 Development of collector

4.3.1.1. Structural and functional design of collector plate

The performance of the collecting plate was assessed based on its ability to effectively guide cashew fruits from the ground into the cup elevator without causing mechanical damage. The results indicated that the inclination angle of the plate played a crucial role in facilitating smooth fruit transfer, particularly due to the irregular shape and limited rolling tendency of cashew apples. A plate inclination of 35° was found to be optimal under the given field conditions, effectively reducing fruit accumulation at the base while allowing a consistent and smooth transition into the elevator cups. This observation aligns with the recommendations of Zeebroeck (2007) for handling non-rolling fruits, where steeper angles enhance collection efficiency. Material selection also influenced performance, aluminium was found to offer an effective balance between low surface friction and structural rigidity, resulting in minimal bruising or damage during pickup. These results highlight the importance of both geometric design and material selection in optimizing the ground-level collection system for cashew fruits.

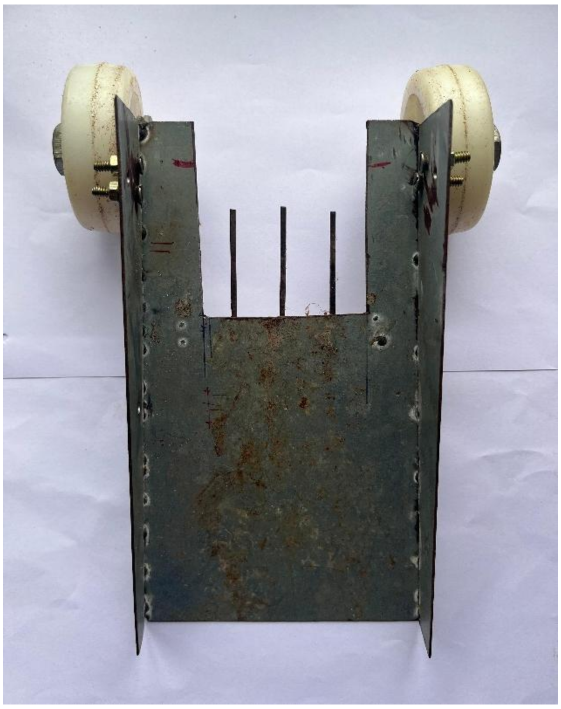

Plate. 4.1 Collector plate

4.3.1.2 Hinge design evaluation for collecting plate

The mechanical design of the collecting plate, which is attached to the conveyor system via hinges, was analysed to determine the bending moment imposed on each hinge during typical operation. This analysis is critical for ensuring that the hinged mechanism can withstand the expected loads encountered during the dynamic collection of cashew apples in the field.

The average weight of a single cashew apple was measured to be approximately 60 g (0.06 kg). Given the design objective for the plate to simultaneously collect 3 to 4 apples, the total load mass ranged from 0.18 kg to 0.24 kg. To accommodate the effects of motion, impact, and vibration during operation, a dynamic load factor of 1.5 was applied to the gravitational load.

The total load W acting at the tip of the collecting plate was calculated using the standard equation:

$$W = m \times g \times \text{Dynamic Load Factor} \qquad \text{From (3.1)}$$

$$W = 0.24 \times 9.81 \times 1.5 = 3.53N$$

The distance from the hinge to the point where the load acts was measured as 25 cm (0.25 m). The resulting bending moment M acting at the hinge line is:

$$M = W \times L = 3.53 \times 0.25 = 0.88Nm$$

With the plate supported by two hinges, the bending moment per hinge becomes:

$$M_{hinge} = M/n = 0.88/2 = 0.44Nm \qquad \text{From (3.2)}$$

This value guided the hinge selection process to ensure that each hinge can safely withstand a minimum of 0.44 Nm of bending moment during field operation. Hinge specifications were chosen accordingly, following the mechanical design standards recommended by Shigley and Mischke (2008), thereby ensuring both safety and durability of the collecting mechanism under dynamic agricultural conditions.

In this system, the hinge mechanism is implemented using a screw acting as a pivot point. No off-the-shelf hinge was used therefore, no manufacturer-rated torque value is applicable. Instead, the screw was selected based on its mechanical strength and expected moment loading. A safety factor of 2.5 was applied to the calculated working moment, leading to a required moment capacity of 1.10 Nm.

$$M_{Rated} = 2.5 \times 0.44 = 1.10 \text{ Nm}$$

4.3.2 Design of picker

4.3.2.1 Material selection

The design of the cup pickers was guided by the need to balance structural integrity with gentle handling of cashew fruits to prevent bruising or mechanical damage during collection. Several materials were evaluated for this purpose, including polyvinyl chloride (PVC), mild steel, and silicone rubber, based on their mechanical properties and suitability for agricultural applications.

PVC was ultimately selected as the primary material for the cup pickers due to its lightweight nature, moldability, and availability in both rigid and flexible forms. The reduced weight helped to minimize the overall load on the conveying system, thereby reducing power consumption and mechanical stress on the moving components. Additionally, PVC offered sufficient structural stiffness to maintain the shape of the picker while still allowing for custom shaping and integration with soft linings, if needed.

While materials such as mild steel offer greater mechanical strength, they would have increased the system’s mass and required additional cushioning (e.g., rubber or foam) to protect the delicate fruit. On the other hand, polymers like silicone rubber and PU provide superior flexibility and cushioning but may lack sufficient rigidity for consistent cup shape retention during operation. Therefore, the use of PVC provided an optimal trade-off between weight reduction, manufacturability, and gentle fruit handling, contributing to the system’s efficiency and operational reliability in the field.

4.3.2.2 Geometry and dimensions

Model 1 – L Shaped

Although the L-shaped cup design is cost-effective and easy to fabricate using standard bending techniques, it presents several drawbacks that can limit its effectiveness in a real-world cashew fruit collection system. The flat horizontal surface may struggle to retain round or irregularly shaped fruits, such as cashew apples, which can easily roll off due to the lack of enclosing walls. Additionally, this shape is not well-suited for scooping fruits that are partially embedded in soil or mixed with field debris, as the sharp angular profile lacks the ability to guide or funnel the fruit gently onto the holding surface. Furthermore, the open structure provides little protection against external elements like wind or impact from surrounding vegetation. These limitations indicate that while the L-shaped cup offers advantages in fabrication and mechanical strength, it does not provide the secure containment and handling finesse needed for efficient and reliable cashew fruit collection in variable field conditions.

Model 2 – J Shaped

While the J-shaped cup offers improved scooping efficiency and reduced spillage compared to simpler designs, it still presents certain limitations that may hinder its performance in the cashew fruit collection system. Although the curved bottom supports better fruit handling, the lack of a frontal or upper containment feature may result in fruits bouncing out under dynamic conditions. The smooth curvature also reduces the frictional resistance that could otherwise help hold the fruit in place during motion. Furthermore, the design may be less effective in densely littered ground conditions, where cashew fruits are partially embedded in soil or surrounded by debris, as the gentle curve may not generate enough forward force to dislodge and scoop the fruit efficiently. These factors suggest that while the J-shape is a step forward in handling and fabrication simplicity, it may still fall short in ensuring maximum containment and adaptability across diverse field environments.

Plate. 4.2 Model 2 – J Shaped

Model 3 – J shaped with slots

J shaped with slot cup is a uniquely contoured fruit-collecting cup fabricated from a single sheet of material with precision bending and slotting. The backplate is perforated with a grid of holes, allowing for secure attachment to the conveyor mechanism and reducing overall weight. The curved profile of the backplate provides structural support and guides the motion of collected fruits upward during transport. What distinguishes this model is its front edge, which consists of three extended, finger-like slots with downward-curved tips. These "fingers" serve multiple purposes: they help in gently scooping cashew fruits from uneven surfaces, provide partial containment to prevent sideward rolling, and reduce bruising by minimizing surface contact pressure. The gaps between the slots allow for dirt and small debris to pass through, reducing clogging during field operation. This model is particularly suited for collecting irregular or partially embedded cashew apples, as the slotted fingers can engage with the fruit more effectively than flat-edged designs. Overall, the fingered cup design combines effective scooping, structural adaptability, and gentle handling—making it a promising candidate for field testing in variable agricultural conditions.

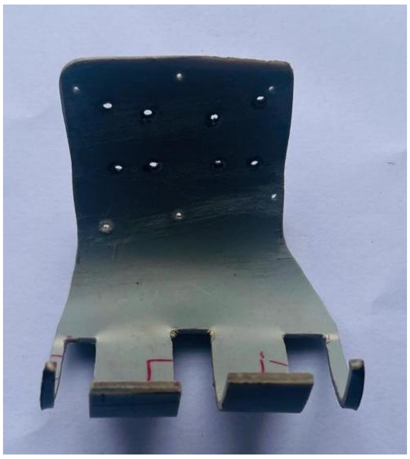

Plate. 4.3 Model 3 – J shaped with slots

4.3.2.3 Cup arrangement and mounting

To ensure efficient and reliable fruit collection, the cup pickers were mounted at regular intervals along the conveyor belt using bolted attachments, providing secure and durable fixation. The spacing between individual cups was a critical design parameter, as it influences both the fruit handling efficiency and the throughput rate of the collection system.

A uniform spacing of 20 cm was adopted based on the average size of cashew apples and the need to provide sufficient clearance for each fruit. This spacing ensured that each cashew fruit had a dedicated cavity for pickup, minimizing the risk of overlapping, jamming, or fruit damage during the collection process. The regular interval also facilitated consistent timing and alignment with the collecting plate, enhancing the overall synchronization and efficiency of the conveying mechanism.

Plate. 4.4 Cup arrangement and mounting

4.3.3 Design of conveyor belt

The developed mechanical fruit collection system features a conveyor belt equipped with picker cups spaced at 20 cm intervals. With a total conveyor length of 1.8 m, the system accommodates nine cups, allowing efficient and organized transport of cashew fruits. Each cup is designed to hold a single fruit, with the average fruit weight considered as 60 g. This configuration ensures that fruits are collected without overlap or jamming, while maintaining a compact system footprint suitable for field operation. The material used for conveyor belt is 2-inch-wide Nylon webbing strap which is having low weight with high strength.

Plate. 4.5 Conveyor Belt

4.3.3.1 Conveyor belt with picker cups

The elevator conveyor is equipped with soft, compliant picker cups mounted uniformly along the belt at 20 cm intervals. As cashew fruits slide down the inclined collection plate, they are directed into the cups through the continuous motion of the belt, driven by a motor-pulley system operating at 30 rpm.

The number of cups per unit length of the conveyor is given by:

$$n = \frac{1}{0.2}$$

$$= 5 \text{ cups}$$

Total number of cups,

$$n_t = 5 \times 1.8$$

$$= 9 \text{ cups}$$

Considering 5 fruits are loaded at a time,

The total load of the belt, considering average fruit weight W_f, is:

$$M = 5*60$$

$$= 3000 \text{ g}$$

$$M = 0.30 \text{ kg}$$

Linear speed of the belt υ,

$$\upsilon = 2\pi \times 0.025 \times 30 / 60$$

$$= 0.0785 \text{ m/s}$$

The throughput of Q_f fruits per hour is given by:

$$Q_f = (0.0785*3600)/0.2 \qquad \text{From (3.3)}$$

$$= 1413 \text{ fruits/hr}$$

However, it is important to note that the theoretical throughput of 1413 fruits per hour represents an ideal scenario based on continuous, uninterrupted operation. In practical field conditions, the machine experiences frequent start-stop cycles, reducing the effective operating time. Additionally, the collection efficiency of the system is influenced by factors such as uneven terrain, fruit orientation, and occasional slippage or misses during pickup. As a result, the actual fruit collection rate is significantly lower than the calculated maximum.

4.3.3.2 Drive system and power transmission analysis

The driving force required to move the belt and the corresponding power requirement is:

$$F = M * g$$

$$= 0.30 \times 9.81$$

$$= 3.629 \text{ N}$$

$$P = F * \upsilon = M * g * \upsilon \qquad \text{From (3.4)}$$

$$= 3.629 \times 0.0785$$

$$= 0.2849 \text{ W}$$

To account for system losses, the motor power is adjusted by the efficiency factor η:

$$P_{motor} = (M * g * \upsilon) / \eta \qquad \text{From (3.5)}$$

Considering η to be 85 %,

$$P_{motor} = 0.2849/0.85$$

$$= 0.3352 \text{ W}$$

Plate. 4.6 Motor

Specifications of the motor:

Brand: INVENTO

Model Number: ISC 677-M

Input Voltage: 220 V

Output Voltage: 12 V

Speed: 30 RPM

Current Rating: 0.12 A

Wattage: 1.44 W

The required power for operating the implement is calculated to be 0.3352 W, considering an overall efficiency of 85%. However, a motor with a rated power of 1.44 W is selected for the design. This provides a substantial safety margin, ensuring that the motor will not be overloaded during operation. The excess capacity accommodates unexpected load variations, startup torque requirements, and minor system inefficiencies not accounted for in the theoretical calculation. Therefore, the selected motor is considered safe and appropriate for the implement, offering both reliability and durability in practical use.

4.3.4 Drive and driven shaft design

The conveyor system incorporates two main shafts: a drive shaft, responsible for transmitting power from the motor to the belt via a pulley, and a driven (idler) shaft, which supports the return side of the belt and helps maintain tension. Both shafts were designed considering the torque transmission requirements, bending loads induced by belt tension, and the mechanical properties of the selected shaft material. This ensured that the shafts could reliably support the conveyor's operational loads while minimizing deflection and mechanical stress during continuous and intermittent operation.

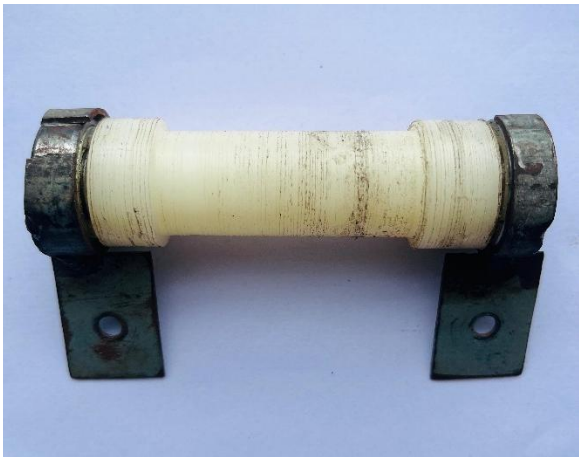

Plate. 4.7 Drive shaft

4.3.4.1 Torque transmission and shaft diameter calculation

The drive shaft was designed to withstand the torque required to move the loaded belt.

Torque T is calculated from the motor power and belt speed:

$$T = (P_{motor} * 60) / 2\pi N \qquad \text{From (3.6)}$$

$$= (1.44 \times 60)/2\pi \times 30$$

$$= 0.46 \text{ Nm}$$

The required shaft diameter d was estimated using the torsional shear stress formula:

$$T = (\pi/16) * \tau * d^3$$

The material we chose for shaft was nylon. One of its main benefits is its lightweight nature, which helps reduce the overall weight of machinery and lowers energy consumption.

Shear stress for nylon was found to be 69 MPa (Bessell & Shortall., 1977).

Solving for d,

$$d = (16T/\pi\tau)^{1/3} \qquad \text{From (3.7)}$$

$$d = \left(\frac{16 \times 0{\cdot}46}{\pi \times 69 \times 10^6}\right)^{\frac{1}{3}}$$

$$d = 0.00324 \text{ m}$$

Verification of shaft Diameter,

A shaft diameter of 2.5 cm (0.025 m) was selected for the system. To verify its theoretical adequacy, the actual shear stress developed under the applied torque was compared to the allowable shear stress of the shaft material (nylon).

Using the torsional shear stress formula,

$$\tau = \frac{16T}{\pi d^3}$$

Substituting the values,

We get π = 0.15 MPa

This value is significantly lower than the allowable shear stress for nylon, which is 69 MPa (Bessell & Shortall, 1977). Therefore, the selected shaft diameter of 2.5 cm is safe, as it provides a wide margin of safety under the expected loading conditions

4.4 DEVELOPMENT OF SEPARATING UNIT

4.4.1 Main Gear Assembly

The main gear assembly, central to the separating unit, was fabricated with a tooth count of 60 and a module of 2 mm, resulting in a pitch diameter of 120 mm and an outer diameter of 122 mm. A bore diameter of 70 mm was chosen to accommodate the central insert, and the gear face width was maintained at 10 mm to ensure adequate engagement and strength. The gear was designed with a standard pressure angle of 20°, offering smooth meshing and load distribution. At the core of the gear, a soft rubber flap was integrated to facilitate nut engagement and enhance the separation process. This rubber inserts, fixed at the gear centre, featured a custom groove that allowed the cashew nut to nest securely during rotation. The flexible nature of the rubber minimized shell damage while maintaining effective grip. Additionally, the flap was engineered to assist in removing the nut post-separation, simplifying the process and reducing the need for additional handling.

Plate. 4.8 Main Gear Assembly

Table. 4.1 Specification of main gear

Teeth z	Module m	Pitch Diameter	Outer diameter	Bore Diameter	Face width	Pressure angle
60	2 mm	120 mm	122 mm	70 mm	10 mm	20°

4.4.2 Motor-Driven Gear

The power transmission system of the separating unit is initiated by an electric motor directly connected to a gear with 15 teeth and a module of 2 mm. This configuration results in a pitch diameter of 30 mm and an outer diameter of 32 mm, with a face width of 10 mm and a bore diameter of 5 mm. A standard 20° pressure angle was employed to ensure smooth meshing with the subsequent gears in the train. This motor-driven gear is one of six gears in the assembly and is mechanically coupled to the main gear, enabling efficient transfer of torque for the nut separation process. The direct shaft-to-gear connection minimizes energy losses and guarantees consistent rotational input to the system. During testing, the gear showed stable performance under dynamic loads, indicating good design compatibility and precise gear tooth engagement.

Table. 4.2 Specification of motor gear

Teeth z	Module m	Pitch Diameter	Outer diameter	Bore Diameter	Face width	Pressure angle
15	2 mm	30 mm	32 mm	5 mm	10 mm	20°

Specifications of the motor:

Brand: ROBODO

Model Number: IJR 523

Output Voltage: 12 V

Speed: 200 RPM

No load Current Rating: 800 mA

Wattage: 9.6 W

Plate. 4.9 Motor

To achieve effective fruit detachment, a torque of 3 Nm was required, based on a detachment force of 30 N applied at a radius of 0.1 m. A 200 RPM electric motor was selected, offering sufficient torque and speed to drive the separating mechanism efficiently. To reduce the speed and increase the torque at the separating unit, a gear ratio of 4:1 was implemented within the gear train.

Using the gear ratio, the output rotational speed is calculated using the relation:

Output RPM = Input RPM / Gear Ratio

= 200/4

= 50 RPM

As a result, the main gear in the separating unit operates at 50 RPM, providing controlled and consistent rotation for reliable nut separation. This reduced speed ensures that adequate pressure is applied for detaching the cashew nut without causing damage to either the nut or the fruit body, thereby enhancing the overall efficiency and safety of the separation process.

4.4.3 Supporting Gears

To maintain smooth and mechanically balanced operation, the main gear is surrounded by four supporting gears, each fabricated with 20 teeth and a module of 2 mm. These specifications yield a pitch diameter of 40 mm and an outer diameter of 42 mm, with a bore diameter of 5 mm and a face width of 10 mm. A standard 20° pressure angle ensures consistent gear meshing and reliable contact with the main gear. The four supporting gears are arranged symmetrically around the main gear to provide structural balance and stabilize its rotational motion. Although these gears are not involved in torque transmission, their presence is critical in preventing misalignment and uneven loading. By distributing mechanical forces uniformly around the main gear, the system experiences reduced vibration and improved longevity of gear teeth.

Plate. 4.10 Supporting Gears

Table. 4.3 Specification of supporting gears

Teeth z	Module m	Pitch Diameter	Outer diameter	Bore Diameter	Face width	Pressure angle
20	2 mm	40 mm	42 mm	5 mm	10 mm	20°

4.4.4 Base Plate and Structural Mounting

All gears including the main, supporting, and motor-driven gears as well as the electric motor were securely mounted on a rigid mild steel (MS) base plate. This base plate served as the structural foundation of the separating unit, ensuring precise alignment of components and minimizing vibrations during operation. The use of mild steel provided the necessary strength and rigidity to withstand the mechanical loads generated during nut-fruit separation. Additionally, the base plate was designed for balanced weight distribution and included provisions for easy access, facilitating routine maintenance and inspection. Its robust construction contributed significantly to the overall stability and operational efficiency of the system.

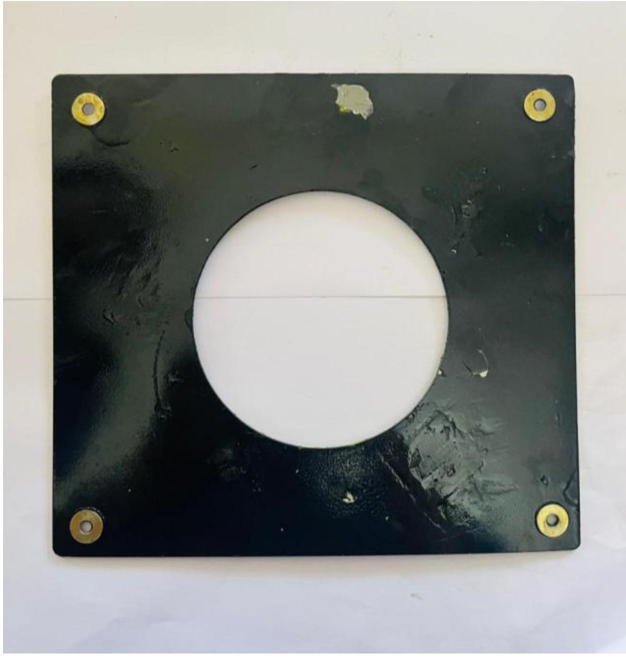

Plate. 4.11 Base Plate

4.4.5 Fabrication via 3D Printing

All components of the separating unit, including gears, rubber inserts, and mounting structures, were fabricated using Fused Deposition Modelling (FDM), a widely used 3D printing technique. Polylactic Acid (PLA) was selected as the printing material due to its ease of use, dimensional accuracy, and adequate strength for prototype testing. The use of 3D printing enabled rapid prototyping, precise customization of geometries, and efficient design iterations. This was particularly advantageous for fabricating intricate features such as the internal groove in the rubber insert, which required high precision with minimal post-processing. The flexibility of the FDM process significantly reduced development time and allowed for quick adjustments during testing, ultimately contributing to the optimization and functional reliability of the separating unit.

4.5 FIELD TEST

To evaluate the practical performance and efficiency of the developed cashew nut collecting and separating machine, a comprehensive field test was conducted under real agricultural conditions. The purpose of the test was to assess how effectively the machine performs in terms of key operational parameters, including the fruit collection rate, nut separation accuracy, labour input reduction, and the overall functionality of the system in a typical cashew orchard setting. By simulating actual field scenarios, the test aimed to validate the machine's design objectives particularly its ability to collect fallen cashew apples efficiently, detach nuts with minimal damage, and operate smoothly over uneven terrain. The test also served to compare the machine's performance against traditional manual methods, thereby highlighting its potential to enhance productivity, reduce human effort, and increase processing speed. Observations and data gathered during the test were critical in identifying both strengths and areas for improvement, providing valuable insights for further refinement and possible scaling for broader field applications.

4.5.1 Picking Efficiency

The picking efficiency of a cashew fruit collector refers to its effectiveness in gathering fallen cashew apples from the ground with minimal fruit loss and physical damage. It is a critical parameter for evaluating the performance of the collection system, as high picking efficiency directly contributes to increased yield, reduced manual labour, and improved post-harvest quality. Several factors influence picking efficiency, including ground surface conditions, distribution pattern of fallen fruits, operating speed of the machine, and design parameters of the picking mechanism such as the angle and flexibility of the collecting plate, spacing between prongs or scoops, and the overall adaptability of the mechanism to field irregularities. The efficiency is calculated using the formula:

$$\text{Picking efficiency} = \frac{\text{Number of fruits collected}}{\text{Total number of fruits}} \times 100$$

A high picking efficiency indicates that the machine can collect a large proportion of the available fruits effectively, thereby improving the overall productivity and sustainability of the harvesting process.

Table. 4.4 Picking Efficiency

Sample No.	No. of fruits collected	Total No. of Fruits	Picking Efficiency (%)
1	4	10	40
2	5	10	50
3	3	10	30
4	4	10	40
5	6	10	60

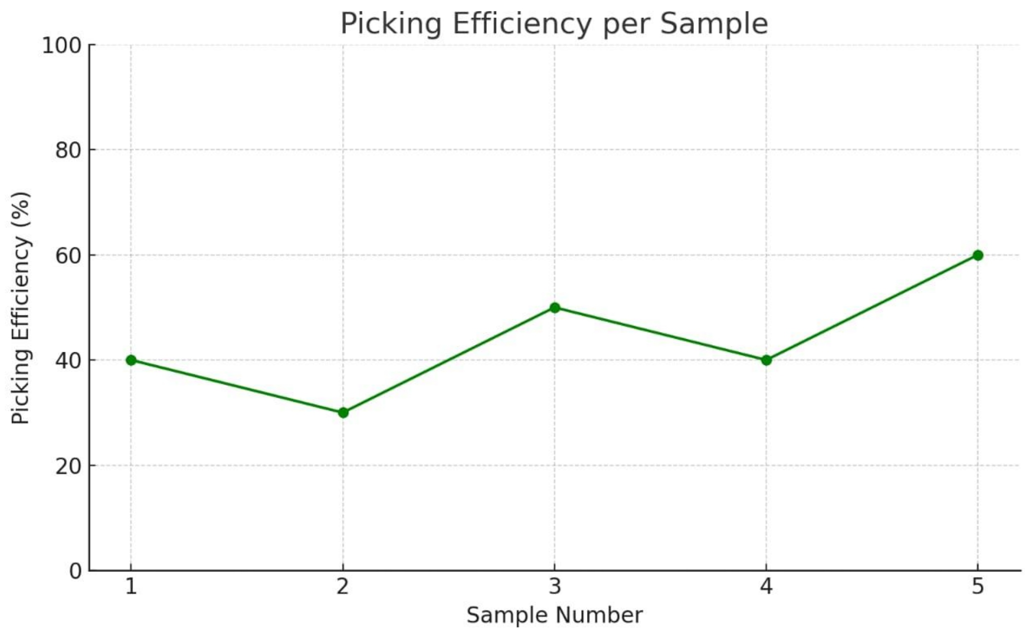

Fig. 4.1 Picking Efficiency

The fruit-picking efficiency showed noticeable variation across the five samples tested. Sample 5 achieved the highest efficiency at 60%, while Sample 3 recorded the lowest at 30%. The average picking efficiency across all samples was 44%, reflecting a moderate level of performance. These results indicate that while the system is functional, there remains considerable scope for improvement in design or operational parameters to enhance overall efficiency.

4.5.2 Conveying Efficiency

Conveying efficiency of the cashew nut and fruit separator was calculated as the percentage of materials successfully transported from the collection point to the delivery point without spillage or damage. A high conveying efficiency indicates smooth and controlled movement of fruits and nuts through the conveyor system.

$$\text{Conveying efficiency} = \frac{\text{Number of fruits collected at delivery point}}{\text{Total number of fruits}} \text{ x } 100$$

Table. 4.5 Conveying Efficiency

Sample No.	No. of fruits collected at delivery point	Total No. of Fruits	Conveying Efficiency (%)
1	5	10	50
2	5	10	50
3	3	10	30
4	4	10	40
5	6	10	60

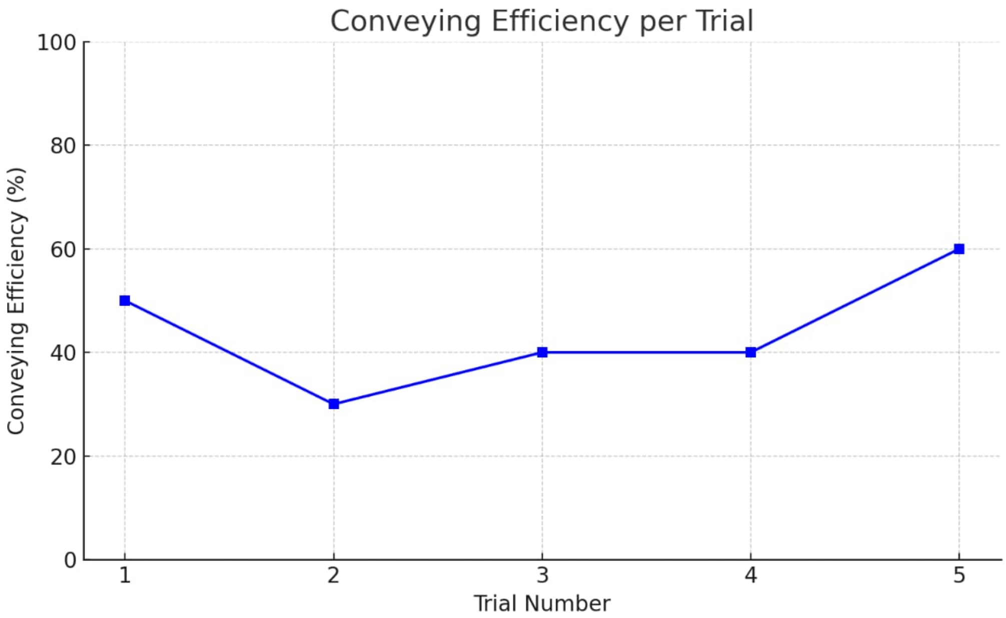

Fig. 4.2 Conveying Efficiency

The conveying efficiency test began with a total of 10 fruits in each trial. The number of fruits successfully collected at the delivery point ranged from 3 to 6. The highest conveying efficiency was recorded in Trial 5 at 60%, while the lowest occurred in Trial 3 at 30%. The average conveying efficiency across all five trials was calculated to be 46%, indicating a moderate level of performance with noticeable inconsistencies in fruit transportation.

4.5.3 Separation Efficiency

The separating unit demonstrated high efficiency by successfully detaching the cashew nut completely within just one rotation, indicating both rapid and effective performance. The detachment angle measured during operation ranged from 180° to 270°, which is consistent with the mechanical design parameters. Under the test conditions, the separating unit achieved a 100% separating efficiency, confirming its reliability and effectiveness in separating nuts from fruits. This performance suggests the system can operate continuously without the need for multiple rotations, thereby improving processing speed and reducing operational time.

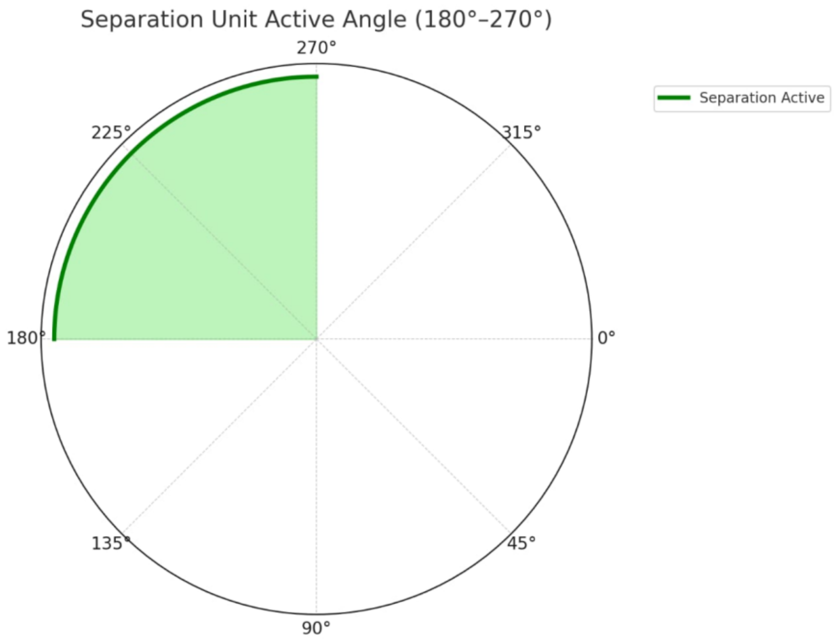

Fig. 4.3 Separation Active angle

Plate. 4.4 Seperating Gears Assembly

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSIONS

The present study focused on the design and development of an integrated system for the collection of cashew fruits and the mechanical separation of cashew nuts from apples. The system was conceptualized to address the limitations associated with manual harvesting, which is labour-intensive, ergonomically strenuous, and inefficient, particularly in small and medium-scale farming operations. The physical and structural characteristics of cashew apples and nuts were first studied to inform the systematic design of the collecting and separating units. Based on these characteristics, a field-operable prototype comprising a collecting plate, conveyor belt with picker cups, and a nut-separating gear assembly was successfully developed and evaluated.

The collecting plate was inclined optimally to facilitate smooth transfer of fruits, while the picker cups fabricated from lightweight and durable PVC ensured secure and gentle handling of fruits during transport. The conveyor system, powered by a low-wattage electric motor, demonstrated sufficient capacity with theoretical throughputs of over 1,400 fruits per hour under ideal conditions. The inclusion of a gear-based separation mechanism, fabricated using 3D printing techniques, enabled effective and damage-minimized detachment of nuts from apples. The supporting structural design ensured mechanical balance, reduced vibration, and promoted operational stability.

Overall, the developed system proved to be technically feasible, ergonomically sound, and economically viable. It successfully demonstrated its potential to mechanize a critical stage in cashew processing, reduce drudgery, improve efficiency, and minimize post-harvest losses. With further refinement and field-scale trials, the prototype may serve as a valuable tool in promoting sustainable cashew production and post-harvest management in India and similar agro-ecological regions.

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DEVELOPMENT OF CASHEW FRUIT COLLECTOR AND CASHEW APPLE AND NUT SEPARATOR

by

KAVYA ANIL (2021-02-016)

SHIFNA SHERIN CT (2021-02-022)

ABHIRAMI KRISHNA (2021-02-024)

ABSTRACT

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND FOOD TECHNOLOGY TAVANUR – 679573

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ABSTRACT

An implement was successfully developed for the efficient collection of cashew apples from the ground and the mechanical separation of cashew nuts from the fruit. This innovation was aimed at addressing key challenges in manual harvesting, such as high labour demand, physical strain, and post-harvest inefficiencies commonly faced in small and medium-scale cashew farming. The prototype integrates three major components: a ground-level collecting plate for scooping fruits, a conveyor system fitted with PVC picker cups for transporting the fruits, and a gear-based separation unit for detaching nuts from apples with minimal damage.

The collecting plate was inclined at 35°, allowing effective fruit guidance without bruising. The picker cups, designed for gentle handling, were mounted at regular intervals along a nylon conveyor belt, powered by a low-wattage motor. The nut separation unit was fabricated using 3D printing technology and featured a main gear with a soft rubber insert, enabling secure grip and efficient nut detachment in a single rotation. The system's design was guided by detailed analysis of the physical characteristics of cashew apples and nuts to ensure compatibility and efficiency during operation.

Field evaluations were conducted to assess the performance of the developed implement. The results showed a picking efficiency of 44%, a conveying efficiency of 46%, and a separation efficiency of 100%. These findings confirm that while the system requires further optimization for improved fruit collection and handling consistency, it performs exceptionally well in nut separation. The implement also significantly reduced physical effort and improved operator comfort by eliminating the need for repetitive stooping and squatting.

Overall, the developed system proved to be technically feasible, economically viable, and ergonomically sound. It demonstrates strong potential for improving productivity, reducing manual labour dependency, and minimizing post-harvest losses in cashew processing. With continued refinement and wider field testing, the implement can contribute meaningfully to sustainable agricultural mechanization in cashew-growing regions.