DEVELOPMENT OF BLACK PEPPER HARVESTER

by

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MALAPPURAM, KERALA, INDIA

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PROJECT REPORT

Submitted in partial fulfillment of the requirement for the degree of

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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 Report entitled **'DEVELOPMENT OF BLACK PEPPER HARVESTER'** is a bonafide record of the project work done by us during the course and that this report has not previously formed on the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Place: Tavanur

Date :

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CERTIFICATE

Certified that the project report entitled **'DEVELOPMENT OF BLACK PEPPER HARVESTER'** is a record of project report work done jointly by **Athira Dinesh (2021-02-006), Gopika .O (2021-02-007), Avanthika Shaji (2021-02-010),** under our guidance and supervision and that it has note previously formed the basis for the award of any degree, diploma, fellowship or associateship or other similar title of another University or Society.

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DEDICATED TO OUR

PROFESSION

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SYMBOLS AND ABBREVIATIONS

Sl.No.	Abbreviation/Notation	Description
1	%	per cent
2	et al.	and others
3	Fig.	Figure
4	DC	Direct Current (used in DC motors)
5	AC	Alternating Current
6	PWM	Pulse Width Modulation (used to control motor speed)
7	RPM	Revolutions Per Minute
8	μ	Coefficient of friction
9	τ	Shear stress / Shear strength
10	A	Cross-sectional area
11	N	Normal force
12	Fc	Cutting Force
13	θ	Crank angle (used in slider-crank mechanism)
14	x	Slider displacement
15	r	Crank radius
16	FDM	Fused Deposition Modeling (3D printing method)
17	ABS	Acrylonitrile Butadiene Styrene (3D printing thermoplastic material)
18	PLA	Polylactic Acid (3D printable plastic)

19	KAU	Kerala Agricultural University
20	FMPE	Farm Machinery and Power Engineering
21	CAD	Computer Aided Design
22	d.b.	Dry Basis (used for moisture content)
23	cm	Centimeter
24	mm	Millimeter
25	V	Volt
26	Arduino UNO	Microcontroller board used for control
27	RULA	Rapid Upper Limb Assessment (ergonomic tool)
28	OWAS	Ovako Working Posture Analysis System (ergonomic tool)
29	3D	Three-dimensional
30	CAD	Computer-Aided Design
31	AC	Alternating Current
32	PWM	Pulse Width Modulation (used to control motor speed)
33	RPM	Revolutions Per Minute (speed of rotating parts)
34	μ	Coefficient of friction
35	τ	Shear stress / Shear strength

36	A	Cross-sectional area
37	N	Normal force
38	Fc	Cutting Force
39	θ	Crank angle (used in slider-crank mechanism)

INTRODUCTION

CHAPTER 1

INTRODUCTION

Agriculture is the backbone of the indian economy, playing a pivotal role in the country's development and sustenance. It is not only a source of livelihood for a significant portion of the population but also a crucial contributor to the nation's food security and economic growth.

Agriculture is the primary sector of the Indian economy, contributing 16-17% (Sahu *et al.,* 2023) of India's GDP and employs about 42-54% (Sahu *et al.*, 2023) of the workforce, making it the largest employment provider in the country. The sector has been instrumental in driving economic growth, particularly during times of economic downturn. For instance, during the first quarter of 2020, agriculture was the only sector to report positive growth, contributing Rs 14,815 crore (Chakraborty, 2024) to the economy.

India is the global leader in the production of milk, pulses, spices, and several other commodities.The sector also plays a critical role in ensuring food security, producing sufficient food, feed, and fiber to sustain over 1.38 billion people, which is about 18% of the world's population (Usera, 2022).

India is the world's leading producer and exporter of spices, contributing over 4 million tons annually and holding a 35% share in the global spice trade (Powar, 2013). Key spices like chilli, turmeric, cumin, and pepper drive both domestic use and exports, with export values rising by 37% in 2021 (N & Bhattacharyya, 2024). Despite opportunities in productivity and quality enhancement (Vinothini & Suthacini, 2024), challenges such as unscientific farming practices and environmental concerns from processing waste remain significant (Sangeeta *et al.,* 2024).

Black pepper is native to India and has been known to Indian cooking since at least 2000 BC. It originated from the Malabar Coast of India, situated in Kerala. Dried fruits of pepper are usually known as peppercorns. Black pepper (*Piper nigrum*), often hailed as the "King of Spices," is one of the most valuable spices globally, with India being one of the top producers and exporters (Wang *et al.,* 2021). Historically, black pepper has played a crucial role in international trade, drawing European merchants to India and contributing significantly to the country's economy. Depending on harvest time and processing, peppercorns can be black, white, green, and red (actually, reddish-brown) in color. Black pepper has remained the most precious and valuable spice in the world. It is the third most added ingredient in food among a wide range of spices. India is one of the largest producers of black pepper, after China and Vietnam. In 2024, India accounted for 11% of global black pepper production. Karnataka is the leading producer in India, contributing about 60% of the total production, followed by Kerala with 30% (Anon, 2024). A wide variety of black pepper is traded at an international level, with India being one of the top five exporters of black pepper, along with Vietnam, Indonesia, Brazil, and Malaysia. Despite its economic significance, black pepper cultivation and harvesting face several challenges, particularly concerning labor-intensive manual harvesting methods.

The harvesting process of black pepper is a physically demanding task, requiring skilled laborers to manually pick the pepper spikes from the climbing vines. The vines, which can grow up to 4 meters in height, necessitate climbing or using ladders for collection. Harvesting is typically performed when the pepper berries turn from green to red but are not fully ripened. This process, however, is not only time-consuming but also results in physical strain for workers, especially in their hands and fingernails, leading to discomfort after prolonged harvesting hours. Additionally, the scarcity of skilled labor and high wage is the significant challenges to farmers. Moreover, manual harvesting is associated with an estimated 10% yield loss due to improper handling and collection. Conventional black pepper harvesting in India is labor-intensive and ergonomically challenging. Workers typically climb pepper vines or use ladders, maintaining awkward postures for prolonged periods, which leads to a high incidence of musculoskeletal disorders, especially in the back, neck, and shoulders (Bharath *et al.*, 2021). Harvested pepper spikes are manually collected and stored in a back-mounted sack or backpack, adding to the physical burden due to the continuous weight carrying during harvesting. Studies using tools like RULA (Rapid Entire Body Assessment) and OWAS (Ovako Working Posture Analysis System) have classified these tasks as high-risk, emphasizing the need for ergonomic interventions (Gopinath *et al.,* 2024). Innovations such as ground-based mechanical harvesters and ergonomic collection systems are being explored to reduce physical strain and improve worker safety. In future, the labour issue is expected to become more critical in terms of both increasing cost and uncertain availability of skilled labourers. Another conventional method for harvesting is using poles attached with knife for plucking.

Black pepper has played a pivotal role in India's international trade, and it is said that the Europeans came to India primarily for this very spice. Indian pepper is grown in the monsoon forests along the Malabar Coast in South India. 'Malabar Garbled' and 'Tellichery Extra Bold' are the celebrated trade varieties. India also offers green pepper in several processed forms: frozen, dehydrated, freeze-dried, and packed in brine.

More than 75 named varieties are known to be cultivated in India. They are distinguished by the names of the areas of cultivation. Introductions from one area to another have also taken place, resulting in the same variety being known by different names in different places. The common varieties of pepper grown in India include Panniyur-1, Panniyur-2, Panniyur-3, Panniyur-4, Panniyur-5, Panniyur-6, Panniyur-7, Subhakara, Sreekara, Karimunda, Panchami, Pournami, Kottanadan, Kuthiravally, Arakulam, Munda, Balankotta, and Kalluvally. Of these, Panniyur-1 is known for being the most successful variety of pepper (Spice Board India, 2023). The pepper plant (*Piper nigrum*) is a perennial woody vine growing up to 4 meters in height on supporting trees, poles, or trellises (Purushothaman *et al.,* 2020). It is a spreading vine, rooting readily where trailing stems touch the ground (George, 2005). The plant can attain a height of 6.096 m or more, but for commercial purposes, it is restricted to 3.048 m (Ravindran, 2000). The plant is propagated by cuttings and grown at the base of trees with a rough, prickly bark to support them (Spice Board India, 2023). Between three or four years after planting, they commence fruiting, and their productiveness ends about the fifteenth year (Ravindran, 2000). The berries are collected as soon as they turn red and before they are quite ripe; they are then dried in the sun to produce black pepper (Sivaraman *et al.,* 2020). The leaves are 50–100 mm long and 30–60 mm broad are arranged in alternatively (George, 2005). The flowers are small, produced on pendulous spikes 40–80 mm long at the leaf nodes, with the spikes lengthening from 70–150 mm as the fruit matures (Sivaraman *et al.,* 2020). Black pepper of commerce is produced from whole, unripe but fully developed berries. The harvested berries are piled up in a heap to initiate browning. Then they are spread on a suitable drying floor after detaching the berries from the stalk by threshing. During sun-drying, berries are raked to ensure uniform color and to avoid mold development. Drying the berries for 3-5 days reduces the moisture content to 10-12% (Mathew *et al.*, 2022). The dried berries are garbled, graded, and packed in double-lined gunny bags. Blanching the berries in boiling water for one minute before sun drying accelerates the browning process as well as the rate of drying. It also gives a uniform, lustrous black color to the finished product and prevents moldiness of berries. However, prolonged blanching should be avoided since it can deactivate the enzymes responsible for the browning process.

To address the challenges faced by small-scale farmers in harvesting black pepper, there is a need to develop a suitable harvesting tool. Manual harvesting methods are labor-intensive, time-consuming, and heavily dependent on skilled labor, which is both scarce and costly. Farmers typically carry harvested pepper in backpacks, leading to serious musculoskeletal disorders such as chronic back pain, neck strain, and shoulder fatigue, especially due to prolonged bending, squatting, and awkward postures maintained over long hours. Additionally, standing for extended periods during harvest contributes to fatigue and posture-related health problems, reducing the overall efficiency of the labor force.

Existing mechanized harvesting tools, while available in the market, are often unaffordable for marginal and smallholder farmers, with prices ranging from ₹30,000 to ₹80,000, depending on the model and capacity. These machines are also bulky, difficult to operate, and not designed with ergonomic considerations, making them unsuitable for uneven terrain and the complex structure of pepper vines. Some may also result in damage to the crop or require extensive maintenance, further adding to operational costs.

Therefore, the development of a cost-effective, ergonomically designed, efficient, and user-friendly semi-automatic harvesting tool is essential. Such a tool would not only improve productivity and reduce dependence on skilled labor but also minimize health risks and make pepper harvesting more sustainable and accessible for small-scale farmers. In view of the above factors, a research program was undertaken to overcome the problems of pepper harvesting with the following objectives:

1. To develop a suitable semi-automatic tool for harvesting black pepper.
2. To evaluate the performance of the developed tool.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

This chapter includes previous works on pepper and different crop harvesters carried out by various investigators.

2.1 MEASUREMENTS OF PHYSICAL PROPERTIES OF BLACK PEPPER

Sumathikutty, *et al.*,(1979) conducted a study on the chemical constituents of black pepper and found that the major constituents of pepper are starch, fibre and protein but more the significant ones are piperine and volatile oil which contribute the pungency and aroma respectively. The white pepper has higher starch content compared to a black pepper.

Murthy & Bhattacharya (1998) studied the moisture-dependent physical and uniaxial compression properties of black pepper berries. They reported that increasing moisture content increased the angle of repose and decreased floatability (especially beyond 14% moisture content). The deformation of berries decreased as moisture content increased. This foundational work highlighted the significance of moisture in modifying black pepper's mechanical behavior.

Ravindran and Babu (2005) offered a comprehensive overview of black pepper's botanical, agronomic, and commercial characteristics. They emphasized India's dominant position in global production during the early 2000s and the critical role of the Western Ghats in sustaining high-quality pepper cultivation.

Prakash *et al.,* (2010) investigated yield stagnation in Kerala, attributing it to factors such as ageing plantations, limited adoption of improved varieties, and pest infestations, despite the availability of better cultivation practices.

Balasubramanian *et al.,* (2013) conducted a detailed study on the physico-mechanical properties of black pepper seeds and reported values for static coefficients of friction on various surfaces. Their findings indicated that the CoF varied depending on the material of the test surface. For instance, higher friction was observed on rough surfaces such as rubber and plywood compared to smoother surfaces like stainless steel. This behavior was attributed to the surface texture and interaction between the seed coat and the contact material.

The two-link planar manipulator is one of the most fundamental configurations in robotics, serving as the basis for modeling more complex mechanical systems. Its kinematic analysis involves determining the end-effector's position using forward and inverse relationships between joint angles and link lengths. Traditional methods often rely on numerical or symbolic computations, which may be insufficient for precise verification. This study presents a novel approach by formally modeling and verifying the kinematic equations of a two-link planar manipulator using higher-order logic in the HOL-Light theorem prover, thus ensuring mathematical rigor and reducing the risk of design errors (Binyameen *et al.,* 2013).

The study by Sruthi *et al*., (2013) investigated the chemical profiles of black pepper (Piper nigrum L.) variety Panniyur-1 collected from various locations, focusing on primary and secondary metabolites. Significant location-wise variations were observed in essential oil, oleoresin, piperine, total phenol, crude fibre, starch, total fat, and bulk density. Notably, bulk density exhibited a negative correlation with essential oil, oleoresin, piperine, total phenol, crude fibre, and total fat, while showing a positive correlation with starch content. These findings suggest that bulk density is inversely related to the concentration of key quality constituents in black pepper, indicating its potential as an indirect marker for assessing quality variations across different cultivation locations.

Rani and Joseph (2014) analyzed the shifting global dynamics in black pepper trade, noting Vietnam's rise as a leading exporter. They observed that Indian exports were affected by high domestic prices and reduced production levels.

Mathew and Suresh (2016) studied India's spice exports and found that black pepper faced stiff competition from low-cost producers. They emphasized the need for maintaining international quality standards and enhancing value-addition for improved export performance.

Bhat and Sindhu (2018) reported a declining trend in the area and production of black pepper in India. Their analysis highlighted how market volatility, labor shortages, and disease outbreaks contributed to this decline, urging policy-level interventions.

Sahu *et al*., (2020) examined export trends of Indian spices, with specific attention to black pepper. They pointed out inefficiencies in supply chains and advocated for better farmer linkages, improved post-harvest technology, and enhanced global branding.

Sharma and Thomas (2021) focused on sustainable cultivation practices, stressing the need for integrated pest management and soil health improvement. Their study emphasized that ecological approaches could boost productivity while preserving long-term viability.

According to the International Pepper Community (IPC, 2022), Vietnam maintained its position as the global leader in pepper exports, accounting for over 35% of world supply. The report noted improvements in yield due to modern techniques and better market access.

2.2 DEVELOPMENT OF FRUITS OR VEGETABLES HARVESTER

Colorio (1987) developed strawberry harvesting machine by bilateral combing. It is designed to select and harvest large strawberries without damage to plants. It used cylindrical brushes rotating in opposite directions to lift the plants and harvested by a comb on a belt rotating perpendicularly to the fruit rows. Good results were obtained in trials.

Gatke *et al.*,(1987) developed an improvement of berry harvester. A soft fruit harvester was modified with the aim of reducing losses to <10% by weight, damage to <5%. Labour requirement to <14man-h/ha and noise emission to <85dB. Harvesting losses were reduced for black and red currants but concluded not good for gooseberries. The damage of the fruit reached at commercially acceptable levels but damage to bushes retained high.

Thuesen *et al.*,(1988) developed a mechanical harvester for strawberry for the processing industry. In a breeding program in Denmark, cultivars have been developed with vigorous, erect fruit stalks and fruits which readily separate from the calyx. The harvester has rotary comb fingers that extend under the fruit clusters, a conveyor belt with a fan that blows of the leaf debris and a size graders for the fruits. The harvester, which can collect the fruit from 1ha in about 10h has capacities of 1500-2000kg/h designed to pick from each field only once, so that cultivars where fruits ripen over a short period are preferable. Plants grown in a solid bed, with all runners retained, are easier to harvest mechanically than plants grown in row with exposed soil between them.

Zabelititz *et al.*,(1989) developed a mechanical harvester for cultivated ligonberries. The machine picks the berries off vaccinium vitis-idaea bushes by means of rotating brushes. The losses after mechanical harvesting is similar to those associated with hand. But the mechanically harvested fruit contained a higher proportion of stalks and grit. The quality of the berries for industrial processing was good, but the mechanical damage they suffered during harvest made them unsuitable for the fresh market.

Babko *et al.*,(1989) developed modern loading conveyor for sugarbeet. The improved loading conveyor was designed to pick up and transport sugarbeet. The conveyor consisted of a spout fixed at 200, which slides along the soil surface picking up the lifted crop, a cross bar which channels soil and vegetable residues away and toothed blades of the rotating drum to transport the sugarbeet into a container. A formula was developed for calculations of drum rotations, depending on the spout throughput, mass of the beet, and number of size of the drum blades.

Bychkov *et al.,* (1989) developed a mechanized fruit harvester. This machine is designed to harvest fruits or nuts from trees with up to 5m crown dia. and 230mm trunk dia. A hydraulic mechanism shakes the trunk of the tree for 1-3sec; the fruits fall on to the wide soft sloping catchment area and is gathered by a central conveyor belt which transport it to one side. Another conveyor transfers the produced into crates. Two operators are needed and up to 80m trees can be harvested.

Varlamov *et al.,* (1990) developed a harvester by picking sea buck thorn fruit by suction of air stream. A mathematical model of forces necessary to detach sea buck thorn fruit from their stem during mechanical harvesting by air suction is derived using vector analysis. In tests up to 99% of the fruit was harvested; productivity increased 4-6 times when compared to manual harvesting.

Vulchev *et al.,* (1991) developed a harvester for harvesting early-to-medium ripening tomatoes by a conveyor. The tomato plants are pruned in advance in preparation and then shaken over a conveyor. 97-98% of the tomatoes could be harvested in this way and 3% impurities were collected. In comparison with manual harvesting, less labour was required but fuel consumption was higher.

Mohammad C. P. (1999) conducted a study on jackfruit harvester for easy harvesting of the jack fruits. The manually operated jack fruit harvester is a handy and simple tool which can ensure safe handling of jack fruits. The special feature of the tool is that a person standing on the ground (ie, without climbing upon the tree) can harvest jack fruits and lower it safely to the ground. The harvester consists of a long telescopic pole with a hook knife at the top. Besides, a rope woven basket attached to a metallic frame tied to a long rope is used for holding the detached fruit and lowering it safely to the ground. The mentioned pole is also used to position the basket for containing the fruit within the basket before its detachment. Now the rope is held firmly after positioning the basket so as to contain the fruit. The operation is so simple that a layman can harvest the jackfruit easily from a height of about 12m. The net weight of the equipment is about 5 to 8 kg and cost around Rs. 1000/-. For harvesting fruits at higher level the pipe can be extended and fixed in position with a screw and wing nut. Women can also use the tool safely. Pole (usually three pipes) Materials: Aluminum or Iron, Standard length of pipe: 400 cm. Minimum length of pole: 420 cm. Maximum length of pole: 1150cm, Basket Diameter: 40 cm ,Height: 50cm, Woven net (nylon rope): 0.3cm, Metal weight: 200gm, Net weight: 5 to 8kg .

Muhammad C P (2005) conducted a study on fruit plucker. The improved fruit plucker is an improved hook type plucker for plucking fruits like mangoes, sapota etc. The net of common plucker is lengthened and extended downwards like a chute. The advantage is that more quantity can be plucked in a batch since the fruits are stored in the net at the bottom of the pole thereby giving a better balance than the conventional top loading type. The cost of the equipment about Rs1000/- for 12m long and it weighs about 6kg. SPECIFICATIONS: Year of development: 2000, Length of pipes: 11.5m, Weight (11.5m): 6kg Chute Net cloth, jute sack, Ring and hook: Mild steel, Clamp: Mild steel, Set screw: Mild steel.

Aneeshya and Krishnanunni (2009–2010) developed a manually operated pepper harvester which was handy and simple tool which can ensure safe handling of pepper. The special feature of the tool is that a person standing on the ground (ie, without climbing upon the tree) can harvest pepper and lower safely to the ground. The harvester consisted of a long telescopic pole with a hook knife at the top.

Aneeshya and Krishnanunni (2009–2010) also developed a pepper harvester. It consisted of a basket to collect the cut pepper after harvest. The basket was set just below the blade with a required angle for proper conveyance through it. A 4mm metal wire was bent in the form of a circular ring of diameter 13.5cm over which nylon net were stitched to form a basket. When the basket is filled it can easily be disposed to the required destination and again the process could be continued.

Rahul *et al.*,(2012) conducted a study to design and develop a pepper plucking equipment. In order to overcome the usability, safety, and ergonomic issue-related problems, five different concepts were established and selected a final model. The final concept was selected based on customer preference. A wire is connected from the hand operating part to the cutting portion in the selected model. The braking mechanism of bicycles has progressed for the cutting of peppercorns. When the hand lever is pressed, the spring gets compressed, resulting in the cutting of peppercorns. The cutting portion was curve-shaped because the stalk's holding is easier with a curve-shaped cutter.

Kumar and Verma (2014) explored the application of analog PWM techniques for controlling the speed of DC motors. Their study highlighted how PWM provides an efficient and low-power solution for motor control by modulating the average voltage supplied to the motor. The PWM method, according to their research, helps in achieving stable speed under varying load conditions, making it a preferred choice over resistive or variable voltage methods.

Kahandage *et al.*, (2017) designed and developed a piece of harvesting equipment for pepper. They considered several factors such as height adjusting, weight-bearing, artificial lighting, easy cutter operation, durability, and safety for designing the equipment. Because the height of vines varies, spikes are at different vine heights, visibility problems due to higher density of leaves and uneven topography of cultivated areas. The maximum height of the pepper vine was 4m, as recommended by the Department of Agriculture. They used the average length of pepper spikes found in the preliminary study to determine the size of the cutter holder and conveying tube.

Ajayan (2022) developed a robotic system for black pepper harvesting to address labor shortages and improve efficiency. The study compared two image processing methods—OpenCV-Haar Cascade and TensorFlow-Faster R-CNN—for identifying mature pepper spikes, with the latter showing superior accuracy (75%). A two-degree-of-freedom robotic arm with a shear-type end effector was designed for plucking and collecting the spikes. The system outperformed manual harvesting in terms of effectiveness and reduced losses, demonstrating the potential of automation in spice crop harvesting.

The paper by Baballe *et al.* (2022) provides a thorough review of various types of servo motors, highlighting their structural differences, control mechanisms, and practical applications. The authors categorize servo motors into five main types—DC, AC, positional rotation, continuous rotation, and linear servo motors—each tailored for specific uses in robotics, automation, and industrial systems. DC servo motors are praised for their quick response and precise control, while AC servo motors are favored in high-accuracy and closed-loop systems. The study emphasizes the importance of control strategies, particularly PID controllers, in enhancing motor performance in terms of speed, torque, and stability. Simulations using MATLAB were conducted to demonstrate the effectiveness of these control systems in real-world scenarios. Furthermore, the paper presents a detailed comparison between AC and DC servo motors, considering factors such as efficiency, noise, maintenance, size, and power output. The review concludes that selecting the appropriate type of servo motor and control system is crucial for achieving optimal performance in application-specific environments.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

This chapter outlines the materials, methodologies, and procedures adopted for the development and testing of a black pepper harvesting machine. Physical and mechanical characteristics of black pepper were conducted towards the design and development of the harvesting mechanism. Details are provided on the materials chosen for constructing the prototype, ensuring they meet the necessary strength, durability, and compatibility for field operations. The design specifications, structural features, and the experimental setup established for conducting performance trials are thoroughly described. Furthermore, the methods employed for both the simulation and fabrication of the machine are explained.

3.1 MEASUREMENTS OF PHYSICAL PROPERTIES OF BLACK PEPPER

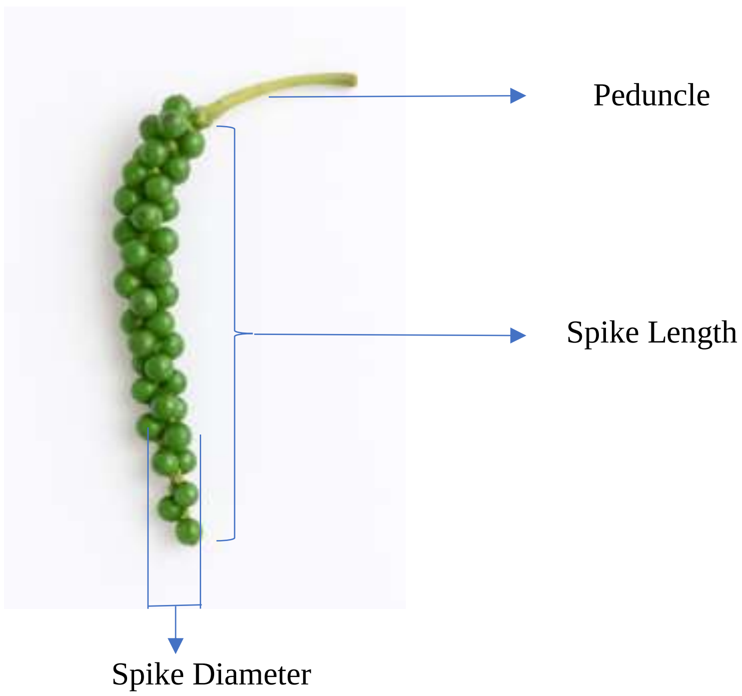

Plate 3.1 Black Pepper

3.1.1 Spike Length

Spike length is the distance from the base of the spike (where it attaches to the peduncle) to its tip, measured using a ruler or vernier caliper. The length of black pepper spikes was recorded to estimate the overall size of individual spikes. This measurement was carefully taken from the uppermost tip of the spike down to its lowermost end, ensuring consistency and accuracy. It is important to note that the peduncle, the stalk that attaches the spike to the main plant, was deliberately excluded from the measurement. By excluding the peduncle, the data accurately reflects only the true length of the spike itself, which consists of the fruit-bearing portion. This standardized approach allows for a more precise comparison of spike sizes across different samples or treatment groups. Spike length is a key factor in the design of a black pepper harvester using a blade and roller mechanism, as it influences the optimal cutting position, blade depth, and rotation of roller. Since spike lengths vary, both the blade and the rotating roller must be precisely adjusted to ensure clean cutting without damaging the vine or leaving portions of the spike behind. Proper consideration of spike length allows for synchronized blade action and roller movement, improving harvesting efficiency and minimizing crop loss.

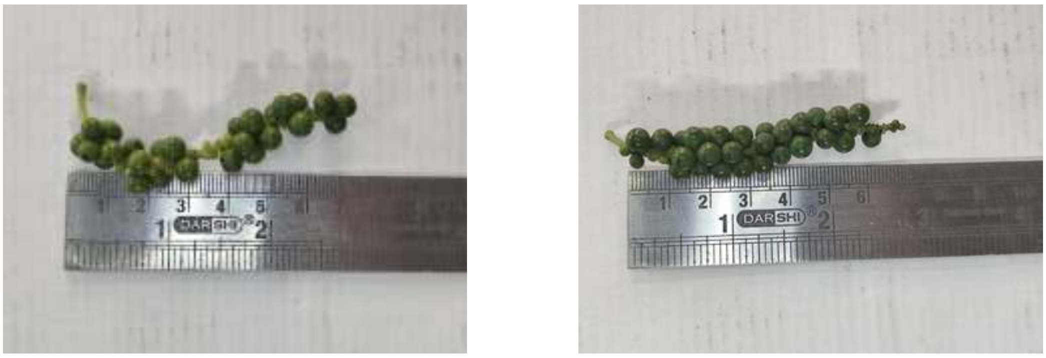

Plate 3.2 Spike length of black pepper (varieties)

3.1.2 Spike Diameter

The thickness of the spike (excluding berries) is measured across its width. The diameters were measured at three specific levels, namely the top end, middle portion, and bottom end of each spike using a vernier caliper . Spike diameter influences the design of roller mechanism which holds the pepper for cutting. The distance between the rollers and the grip provided by the sponge or rubber material must be carefully adjusted based on the average spike diameter. If the diameter is too small and berries are not present, the rollers may fail to grip the spike effectively, resulting in missed or incomplete harvesting. On the other hand, if the rollers are too tight, they may damage the spike or berries. Therefore, proper consideration of spike diameter ensures optimal roller spacing and grip, enabling effective handling of the spikes and improving the overall efficiency and reliability of the harvesting process.

Plate 3.3 Spike Diameter of black pepper (varieties)

3.1.3 Number of berries / spike

A spike is the fruiting structure of the black pepper plant, on which the berries grow. The number of berries in a spike is measured by counting manually or using image analysis software for more precise assessment. The number of berries in a spike is significant in harvester design because it affects how the spike interacts with the rollers. If there are too many berries, they may get stuck or crushed between the rollers, causing damage and reducing quality. Conversely, if there are too few berries, the spike may slip or be held loosely, leading to inefficient harvesting. Proper consideration of berry count helps in adjusting roller pressure and spacing to ensure smooth handling and minimize crop loss.

3.1.4 Co-efficient of friction

The coefficient of friction (μ) is defined as the ratio of the force of friction (F_f) between two bodies to the normal force (N) pressing them together. The equation is given by:

$$\mu = \frac{F_f}{N} \qquad \text{(Zhang \textit{et al.}, 2022)}$$

The coefficient of friction is measured using a tribometer or friction tester, or it can be calculated using the above mentioned equation. The static coefficient of friction for black pepper was determined using various surfaces, including plywood, galvanized iron, mild steel, and aluminum sheets, which are commonly used in storage structures. The coefficient of friction increased linearly with moisture content, indicating that as the moisture level rises, the frictional resistance of black pepper also increases (Zhang *et al.*, 2022).

Among the tested surfaces, the coefficient of friction was highest against plywood, followed by mild steel, galvanized iron, and aluminum, which had the lowest values due to its smoother surface. The increase in the coefficient of friction with moisture content may be attributed to the berries becoming rougher, which diminishes their sliding characteristics. The coefficient of friction ranged from 0.705 to 0.936 as moisture content increased from 3.3% to 18.1% (d.b.) (Balasubramanian *et al*., 2013). The coefficient of friction is crucial in selecting roller material for a black pepper harvester because it determines how well the rollers can grip the pepper spikes without slipping. A suitable coefficient ensures the rollers hold the spikes firmly to enable efficient harvesting without damaging the berries or spikes. If the friction is too low, the spikes may slip and reduce harvesting efficiency; if too high, it may crush or damage the produce. Therefore, choosing a roller material with an optimal coefficient of friction balances grip and gentle handling for effective harvesting.

3.1.6 Cutting Force

The force required to cut through the spike or peduncle (the stalk holding the spike). The cutting force required for harvesting black pepper refers to the amount of force needed to detach the pepper spikes from the vine. This force can vary depending on factors such as the maturity of the spike, the thickness of the stalk, and the sharpness or type of cutting tool used. Generally, the spikes are removed manually or with simple tools, and the force needed is moderate, as the stalks are relatively soft. Efficient harvesting depends on minimizing the required cutting force while ensuring clean removal to avoid damage to the plant or the produce.

3.1.7 Length of peduncle

The length of the stalk (peduncle) that connects the spike to the main plant stem. The peduncle refers to the stem that connects the fruit to the main plant. Its length is determined by measuring the distance from the uppermost point of the pepper spike, where the fruit is attached, down to the node on the stem from which the peduncle extends. This measurement was carefully recorded using a steel ruler for accuracy. The peduncle plays a crucial role in supporting the fruit and facilitating its connection to the plant, and understanding its length provides valuable insight into the plant's growth and development and in determining the movement and positioning of the cutting blade in mechanical harvesters. A longer peduncle provides a clear and accessible area for the blade to make an accurate cut without damaging the pepper spike, thus ensuring the quality of the harvested product. Conversely, a shorter peduncle requires more precise blade control and alignment to avoid cutting into the spike or nearby branches. Therefore, understanding the average peduncle length helps in designing the blade's path, angle, and cutting mechanism to optimize harvesting efficiency while minimizing crop damage.

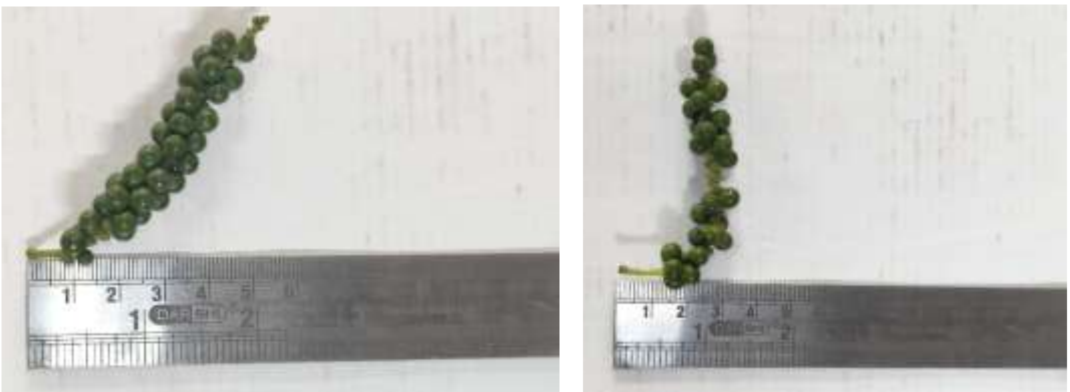

Plate 3.4 Length of peduncle of black pepper (varieties)

3.1.8 Diameter of the peduncle

It is the thickness of the peduncle. The diameter of the peduncle was measured to estimate the size of the pepper peduncle. The diameter of the peduncle plays a significant role in determining the cutting force required in a black pepper harvester. As the diameter increases, the amount of plant tissue the cutting blade must penetrate also increases, leading to higher resistance and a greater force requirement. This is because thicker peduncles have more fibrous and lignified tissues, which are tougher to cut. Therefore, understanding the relationship between peduncle diameter and cutting force is essential for designing efficient cutting mechanisms that can minimize energy consumption while ensuring clean and effective harvesting.

Plate 3.5 Diameter of peduncle of black pepper (varieties)

3.2 DESIGN OF BLACK PEPPER HARVESTER

3.2.1 Frame or Structure

When selecting materials for the frame of a black pepper harvester, key considerations include strength-to-weight ratio, durability, manufacturing ease, and resistance to environmental conditions. Common materials such as PVC, 3D-printed thermoplastics like PLA and ABS, aluminium, and steel each exhibit distinct characteristics that influence their suitability in agricultural machinery. PVC is often considered due to its low cost, corrosion resistance, and ease of assembly. However, it has limitations in terms of mechanical strength and can become brittle under impact or low temperatures (Shih, 2000). 3D-printed materials, particularly PLA and ABS, are gaining attention for their customizability and ability to produce complex geometries. Among these, ABS has shown favorable results in lightweight applications due to its moderate strength, good impact resistance, and dimensional stability, making it useful for components where weight reduction is crucial (Tymrak *et al.*, 2014). PLA, while biodegradable and easy to print, tends to exhibit brittleness and low thermal stability, which limits its use in load-bearing or outdoor conditions (Tymrak *et al.*, 2014). On the other hand, aluminium remains a popular choice for frames requiring a balance of strength, corrosion resistance, and low weight. It allows for efficient design while maintaining structural integrity in field conditions (Davis, 1993). Steel, though heavier, provides exceptional tensile strength and durability, making it suitable for high-stress applications, albeit at the expense of weight and potential corrosion (Degarmo *et al.*, 2011). In a frame structure, there are two main parts:

3.2.1.1 Main frame

The main frame is the base part that provides strength and support to the whole setup. It holds all the important components and keeps everything steady and in place.The components are:-

- Roller- sponge
- Roller rod
- Connecting rod
- Moving Blade
- Stationary blade
- Linkages
- Limit switch
- DC motor
- Servo motor

3.2.1.2 Top frame

On top of main frame sits the top frame, which is usually lighter. Both parts work together to keep the structure stable and functional. Actuating rod that activates a limit switch when the top surface of the frame comes into contact with a node on the pepper vine. Enabling precise positioning and control during harvesting.

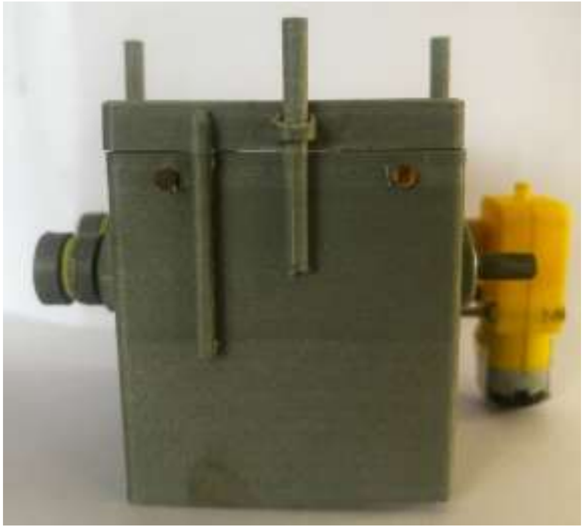

Plate 3.6 Frame

3.2.2 Holding roller mechanism

In a black pepper harvester, the outer cover of the rollers plays a critical role in handling the delicate pepper berries without causing damage. Several materials can be considered for the outer cover, such as rubber, foam, silicone, fabric, and PVC. Rubber, while offering grip, can be too hard, potentially damaging the berries, and may also wear out quickly (Raghavan *et al.,* 2019). Foam materials provide cushioning but can compress excessively or tear under continuous use (Prakash *et al.*, 2021). Silicone and soft polymers offer durability and grip but are often expensive and less accessible for agricultural machinery. Fabric covers can absorb moisture, degrade faster, and lose grip over time, while PVC is rigid, smooth, and provides poor grip, increasing the risk of slippage and damage. For efficient and safe pepper processing, the outer cover must be soft enough to cushion the berries, provide adequate grip to prevent slipping, and conform to the irregular shape of the berries to distribute pressure evenly. Considering these requirements, we selected sponge as the outer cover for the rollers, as it combines softness, grip, pressure distribution, and cost-effectiveness, ensuring gentle and efficient processing of the pepper berries.

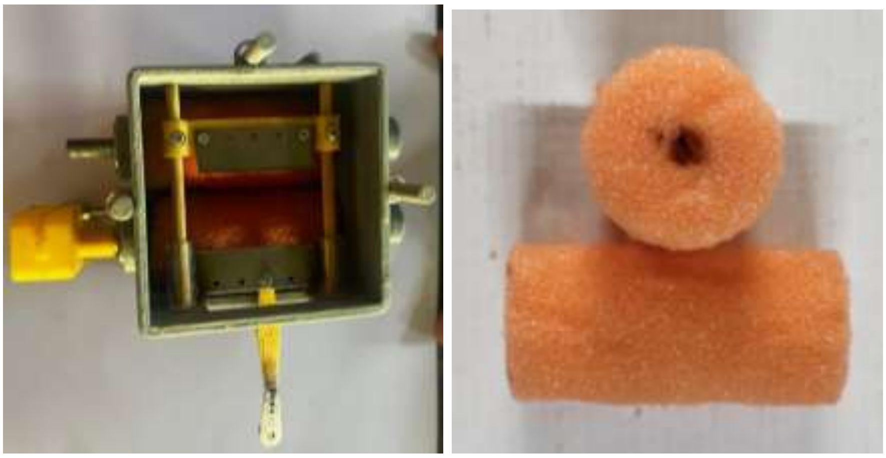

Plate 3.7 Roller

3.2.3 Cutting mechanism

3.2.3.1 Slider Crank Mechanism

The slider-crank mechanism is a basic mechanical system used to convert rotary motion (circular) into reciprocating motion (back-and-forth) or vice versa.

1. Crank - The rotating arm connected to the motor shaft (like your servo motor).
2. Connecting Rod - Connects crank to the slider; it transfers motion.
3. Slider - Moves linearly, this is where the blade is attached.
4. Fixed Frame - The base that holds everything together.

Stroke displacement is the linear displacement of the slider (or blade) from its initial position as the crank rotates through an angle θ. It represents how far the slider has moved at a specific crank angle.

$$x=2r\cdot\sin(\theta/2)$$ (Uicker *et al.*, 2010)

Where:

- x = Blade displacement (stroke covered at any instant)

- r= Crank radius
- θ = Crank angle (in degrees or radians, depending on calculator setting)

Plate 3.8 Cutting blade with linkage

3.2.4 Drive mechanism

In the black pepper harvester, the drive mechanism is engineered to transmit power efficiently from a DC motor to the rollers, ensuring smooth and controlled pepper processing. The DC motor is directly connected to one of the rollers, serving as the primary driver. The second roller receives power through a belt and pulley system**,** where pulleys are affixed to both rollers and connected via a belt. This belt is arranged in a crossed configuration, causing the two rollers to rotate in opposite directions**,** both turning inwards toward each other. This inward motion is crucial for gently gripping and feeding the pepper berries into the harvester, preventing them from slipping away or being ejected. Opting to drive only one roller simplifies the design, reduces the number of components, and avoids unnecessary complexity in the power transmission system.

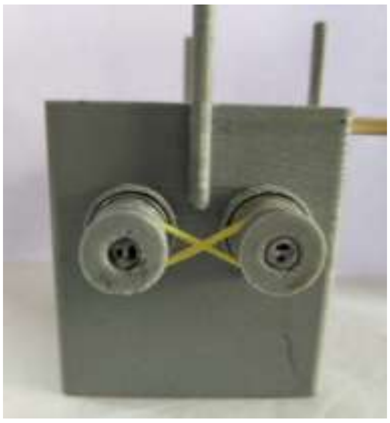

Plate 3.9 Belt and Pulley

3.2.5 Power source

In the black pepper harvester, a battery is used to power the DC motor that drives the rollers. This setup provides a portable and efficient solution for field use, eliminating the need for external power sources. The battery supplies the required electrical energy to rotate the motor, which in turn operates the rollers at the desired speed. By using a battery-powered system, the harvester remains lightweight, easy to handle, and suitable for off-grid agricultural operations.

Plate 3.10 Battery

3.2.6 Control Unit

3.2.6.1 Arduino Microcontroller

Arduino is an open-source microcontroller platform designed for easy programming and interaction with the environment using sensors. It was first introduced in 2005.The Arduino platform consists of both hardware (the Arduino development board) and software (the Arduino IDE), allowing users to write and upload code easily.

The microcontroller serves as the brain of the Arduino board, capable of receiving and sending information to connected peripheral devices (Ismailov and Jo‘rayev 2022).

Arduino IDE is a free, open-source software that provides ready-to-use libraries, making it easier for developers to create projects without starting from scratch. Arduino microcontrollers can connect to the internet, enabling data transmission via HTTP requests, which enhances their functionality in various applications. The platform is widely used in educational settings and research, providing a quick tool for developing small projects involving sensors.

Arduino Uno is a widely used microcontroller board. The board includes multiple digital and analog input/output pins, allowing connections to various sensors and actuators. It can be powered through USB or an external power supply, offering flexibility in usage. Arduino Uno supports numerous libraries and examples, facilitating quick implementation of functionalities. Its simplicity and versatility make it suitable for easy cutting mechanism.

Plate 3.11 Arduino Uno

3.2.6.2 Servo Motors

A servo motor is a type of motor that includes an encoder and is used with controllers for closed-loop control and feedback, allowing for high precision in applications like automation and robotics. There are different types of servo motors, including positional rotation, continuous rotation, and linear servo motors, each serving specific applications. Positional rotation servo motors can rotate approximately 180 degrees and are commonly used in radio-controlled devices, such as cars and aircraft. Continuous rotation servo motors can rotate indefinitely in either direction, controlled by speed and direction commands, making them suitable for applications like mobile robots. DC servo motors utilize a separate DC source for winding control, providing fast response times due to low armature inductive reactance, and are often used in CNC machinery. AC servo motors are designed for high accuracy and precision, often featuring better bearings and higher voltage designs to achieve greater torque (Baballe and Bello, 2022).

Plate 3.12 Servo Motor

3.2.6.3 Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) is a widely used technique for controlling the speed of DC motors by adjusting the average voltage supplied to the motor (Rex and Praba, 2018). It works by rapidly switching the power supply on and off, with the proportion of "on" time (duty cycle) determining the effective power delivered. A higher duty cycle increases motor speed, while a lower duty cycle reduces it (Priyanka and Mariyammal, 2018). PWM offers several advantages, including energy efficiency, precise speed control, and reduced heat generation in the control circuit (Rex and Praba, 2018). It is commonly implemented using microcontrollers, motor driver ICs, and sensors to monitor and adjust speed in real time, making it suitable for a range of industrial and consumer applications (Priyanka and Mariyammal, 2018).

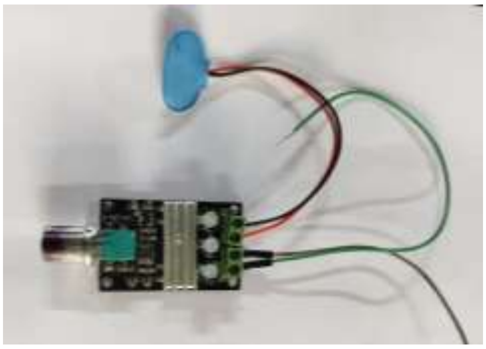

Plate 3.13 PWM

3.3 CAD MODEL

3.3.1 Soild Works

Solid Works is a 3D computer-aided design (CAD) software widely used for designing and modeling mechanical components and products. It offers a variety of tools, including sketching, extruding, sweeping, and lofting, to create detailed 3D models that can be quickly modified for rapid prototyping and iteration. Beyond modeling, SolidWorks includes powerful analysis tools such as simulation, motion analysis, and stress testing, which help engineers evaluate whether a design will perform reliably under real-world conditions. By applying constraints like fixtures and loads, users can perform static and dynamic analyses to understand how a part or assembly will behave under different scenarios. Solid Works also provides advanced visualization tools, such as contour plots and deformation animations, that make it easier to interpret analysis results and improve the design accordingly.

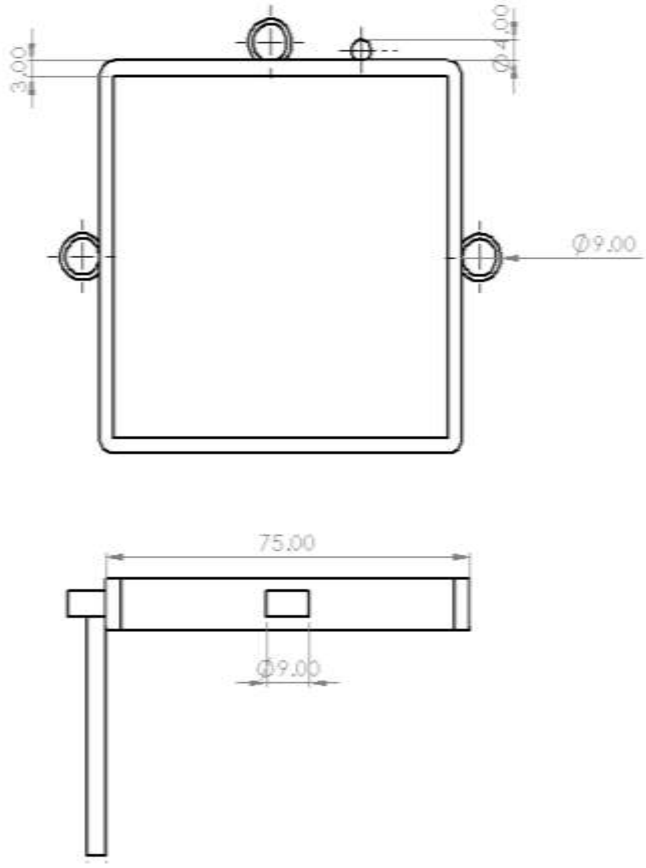

Fig 3.1 Top and side view of Top frame

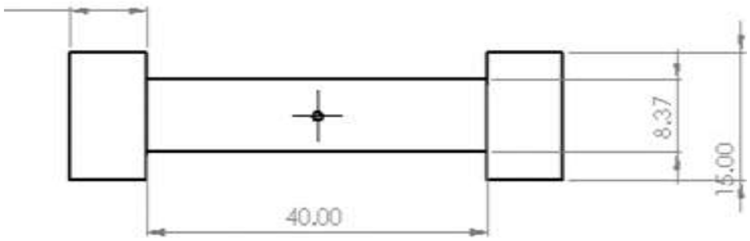

Fig 3.2 Blade

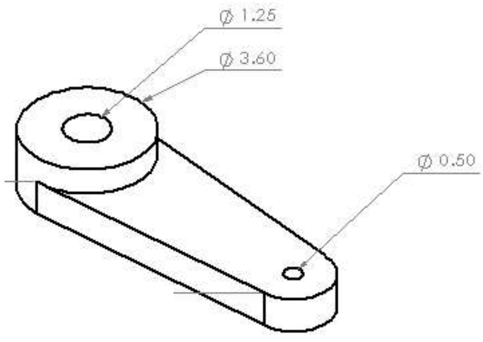

Fig 3.3 Link 1

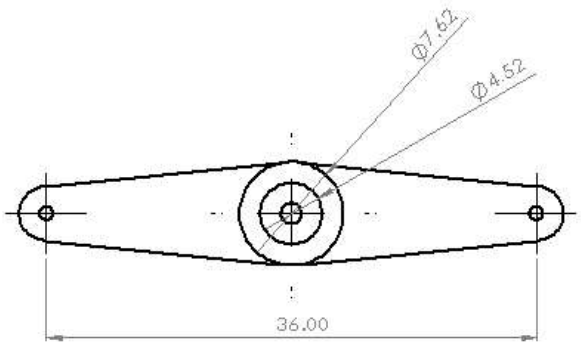

Fig 3.4 Link 2

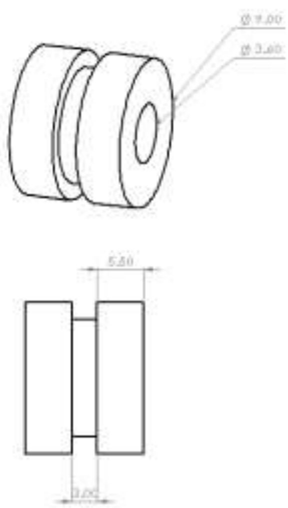

Fig 3.5 Pulley

3.4 DEVELOPMENT AND FABRICATION PROCESS

3.4.1 3D Printing

3D printing, also known as additive manufacturing, involves creating physical objects from a geometrical representation through the successive addition of materials. This process allows for the layer-by-layer deposition of material directly from a computer-aided design (CAD) model.

- Emergence and Growth : The technology has rapidly emerged as a flexible and powerful technique in the advanced manufacturing industry, experiencing significant expansion since its commercialization in the 1980s by Charles Hull. It is now widely utilized across various sectors, including manufacturing, aerospace, and medical applications.
- Applications : 3D printing is used to produce a diverse range of products, such as artificial heart pumps, jewelry, 3D-printed corneas, and components for aerospace and food industries. This versatility highlights its potential in both functional and aesthetic applications.
- Materials Used : Various materials are employed in 3D printing, including polymers, metals, ceramics, and composites. Each material type offers unique properties suitable for specific applications, such as low weight and processing flexibility in polymers, or high strength and corrosion resistance in metal alloys.
- Materials Extrusion : This is a widely used 3D printing technology that allows for the printing of multi-materials and multi-color objects, including plastics, food, and living cells. It is known for its low cost and capability to produce fully functional parts.
- Fused Deposition Modelling (FDM): A specific type of materials extrusion, FDM uses thermoplastic filaments, such as acrylonitrile butadiene styrene (ABS), which is heated and extruded layer by layer to form parts. ABS is favored for its strength, flexibility, and ease of use in 3D printing.
- Temperature Considerations: The extrusion process requires precise temperature control to ensure proper melting and flow of the thermoplastic material. ABS typically requires a nozzle temperature of around 210-250 °C for optimal printing .

- Ceramic Materials : 3D printing technology can also utilize ceramics, such as alumina and bioactive glasses, which are processed to create complex shapes with high density and mechanical strength. This capability allows for applications in high-tech industries, including aerospace and biomedical fields.
- Mechanical Properties : The optimization of printing parameters enables the production of ceramic parts without large pores or cracks, enhancing their strength and durability (Shahrubudin *et al*., 2019).

Plate 3.14 3D Printer

3.4.2 Collecting Method

In the black pepper harvester, the collecting mechanism is thoughtfully designed to enhance efficiency and reduce fruit loss during operation. It features a fine, flexible mesh material securely attached below the main frame of the device. This mesh forms a soft, suspended compartment that gently receives the harvested pepper panicles immediately after they are cut. Its flexible yet durable structure adapts to the movement of the harvester, ensuring that the panicles fall safely into it without bouncing out or getting damaged. The breathable nature of the mesh allows airflow, which helps prevent moisture buildup and keeps the collected produce fresh until unloading.

Positioning the mesh directly beneath the main frame ensures that the panicles do not fall to the ground, eliminating the need for repeated bending or manual collection and keeping the harvest clean and contamination-free. The structure is large enough to hold a considerable amount of material, allowing the operator to continue working without frequent stops to empty the contents. When the mesh reaches its holding capacity, it can be easily unloaded, either by detaching or by inverting a section, depending on the design. This simple yet effective mechanism reduces the physical strain on the operator and increases the speed and convenience of the harvesting process, making it highly suitable for large-scale or repeated use in pepper farms.

Plate 3.15 Collecting bag

3.5 COST ANALYSIS

The development of a black pepper harvester involves the integration of mechanical and electronic components designed to improve harvesting efficiency, reduce labor dependency, and ensure timely collection of pepper berries. Before proceeding with the fabrication or implementation of such a device, it is essential to evaluate the overall costs involved. This cost analysis outlines the estimated expenses for key components used in the construction of a basic semi-automatic black pepper harvester. It includes materials such as structural elements, electronic control units, actuators, power sources, and other supporting accessories. Understanding the cost breakdown helps in budget planning, economic feasibility assessment, and potential scaling for commercial applications.

RESULTS AND DISCUSSIONS

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 MEASUREMENTS OF PHYSICAL PROPERTIES OF BLACK PEPPER

4.1.1 Spike Length

Table 4.1 Spike length of black pepper

SAMPLE NO.	KARIMUNDA (cm)	PANNIYUR (cm)
1	8.2	17.5
2	7.5	16.8
3	9.1	18.9
4	8.7	19.3
5	7.8	20.1
6	8.4	18.2
7	9.0	21.0
8	7.9	17.3
9	8.1	19.6
10	8.5	20.4
Average	8.32	18.91

The spike length of black pepper shows significant variation between the traditional variety Karimunda and the hybrid variety Panniyur 1. Based on sample data, Karimunda recorded an average spike length of 8.32 cm, while Panniyur 1 exhibited a substantially longer average spike length of 18.91 cm. This clearly highlights the superior spike development in Panniyur 1, which is one of the key factors contributing to its higher yield potential. The increased spike length in hybrid varieties like Panniyur 1 results in more space for berry formation, thereby enhancing overall productivity when compared to traditional varieties like Karimunda.

4.1.2 Spike Diameter

Table 4.2 Spike Diameter of black pepper

SAMPLE NO.	KARIMUNDA (cm)	PANNIYUR (cm)
1	0.42	0.58
2	0.39	0.61
3	0.44	0.63
4	0.41	0.56
5	0.38	0.59
6	0.43	0.60
7	0.40	0.62
8	0.37	0.55
9	0.36	0.57
10	0.39	0.60
Average	0.399	0.591

The spike diameter of black pepper also shows noticeable differences between the traditional variety Karimunda and the hybrid variety Panniyur 1. Based on measurements from 10 samples, Karimunda recorded an average spike diameter of 0.399 cm, whereas Panniyur 1 showed a significantly larger average diameter of 0.591

cm. The thicker spikes observed in Panniyur 1 are advantageous for supporting a greater number of berries, thereby contributing to its higher yield potential. In contrast, the thinner spikes of Karimunda, though associated with good quality, generally result in lower productivity. This difference in spike diameter reinforces the suitability of Panniyur 1 for commercial cultivation where yield is a priority.

4.1.3 Number of berries / spike

Table 4.3 Number of berries / spike

Sample No.	Karimunda (berries/spike)	Panniyur 1 (berries/spike)
1	52	102
2	48	97
3	55	110
4	50	105
5	53	98
6	47	100
7	49	95
8	51	108
9	46	99
10	54	103
Average	50.5	101.7

The number of berries per spike is a key indicator of yield potential in black pepper varieties. Based on data from 10 samples, the traditional variety Karimunda recorded an average of 50.5 berries per spike, while the hybrid variety Panniyur 1 showed a much higher average of 101.7 berries per spike. This nearly twofold increase in berry count per spike for Panniyur 1 highlights its superior productivity and suitability for commercial cultivation. The higher number of berries is directly linked to its longer and thicker spikes, providing more surface area for berry development. In contrast, Karimunda, though known for its quality, falls behind in terms of quantity, making Panniyur 1 a more efficient choice for maximizing yield.

4.1.4 Co-efficient of friction

The coefficient of static friction between green pepper and sponge material is an important factor when designing handling or processing systems involving soft, cushioning surfaces. While the referenced study does not provide direct measurements for sponge, it reports a coefficient of static friction of 0.982 between green pepper and soft polyvinyl chloride (PVC), a material with comparable surface characteristics. Given the porous and slightly more grippy texture of sponge compared to PVC, the coefficient of friction between green pepper and sponge can be reasonably estimated to lie within the range of 0.95 to 1.05. This high frictional resistance suggests that sponge surfaces would provide effective support and reduce slippage during gentle handling operations, making them suitable for applications where product protection and stability are prioritized.

4.1.7 Cutting Force

In the design of cutting mechanisms for agricultural tools like a black pepper harvester, accurately estimating the cutting force is essential to ensure clean cuts without damaging the plant or overloading the mechanical system. The cutting force primarily depends on the shear strength of the material being cut and the cross-sectional area involved. Additionally, frictional resistance between the cutting blade and the material contributes to the total force required. Hence, both material properties and mechanical contact factors must be considered to determine the total cutting force accurately.

$F_c = \tau.A+\mu.N$

T = shear Strength of the stem material (N/m^2)

A = Cross sectional Area of the stem (m^2)

μ = Co-efficient of friction b/w blade and the stem

N = Normal Force exerted by the blade on the stem (N)

Stem Diameter (d) =Approx 1mm

coefficient of friction $\mu = 0.95$

Normal Force N = 8

$\tau = 2.5, N/mm^2$

$F_c = (2.5)\times(3)+0.95\times8$

$= 15.1$ N

4.1.9 Length of peduncle

Table 4.4 Length of peduncle of black pepper

Sample No.	Karimunda (cm)	Panniyur 1 (cm)
1	1.8	3.5
2	2.0	3.2
3	1.9	3.4
4	1.7	3.6
5	2.1	3.3
6	1.8	3.7
7	2.0	3.5
8	1.9	3.4
9	1.6	3.3
10	2.0	3.6
Average	1.88	3.45

The length of the peduncle plays an important role in supporting the spike and facilitating nutrient flow in black pepper plants. In the present comparison, Karimunda exhibited an average peduncle length of 1.88 cm, whereas Panniyur 1 showed a significantly longer average of 3.45 cm. The longer peduncle in Panniyur 1 contributes to better spike orientation, increased exposure, and potentially improved nutrient transport to developing berries. This trait, along with longer and thicker spikes, further enhances the yield efficiency of Panniyur 1. Meanwhile, the shorter peduncle in Karimunda reflects its compact and traditional growth habit, which may be favorable for quality but limits overall yield performance.

4.1.10 Diameter of the peduncle

Table 4.5 Diameter of peduncle of black pepper

Sample No.	Karimunda (cm)	Panniyur 1 (cm)
1	0.22	0.35
2	0.20	0.34
3	0.21	0.36
4	0.23	0.33
5	0.19	0.37
6	0.20	0.35
7	0.21	0.34
8	0.22	0.36
9	0.20	0.35
10	0.21	0.36
Average	0.209	0.355

4.2 DESIGN OF BLACK PEPPER HARVESTER

4.2.1 Frame or Structure

In summary, the performance of materials like ABS highlights the potential for lightweight agricultural equipment, particularly where reduced weight, custom design, and moderate mechanical strength are desirable. However, for applications requiring higher structural strength, metals like aluminium or steel may still be preferred.

4.2.2 Picking roller mechanism

In black pepper harvester, the rollers are made by wrapping sponge around a small rod with a diameter of 7mm. This combination is chosen because the sponge provides a soft, compressible surface that gently grips the delicate pepper berries without causing bruising, crushing, or cracking. The porous texture of the sponge enhances the grip on the berries, holding them securely as they move through the harvester. The 7mm rod acts as a sturdy core, supporting the sponge layer while keeping the roller compact enough to maintain precise control over the pressure applied. Using a larger rod would increase roller rigidity and size, reducing the sponge's ability to conform to the irregular shapes of the berries, which could lead to slipping or damage.

The rollers rotate at around 305 revolutions per minute (RPM), a speed measured accurately using a tachometer. This speed is carefully selected to balance efficiency and gentle handling. At 305 RPM, the rollers spin fast enough to process a good volume of pepper berries steadily, ensuring a continuous flow and good throughput. Simultaneously, the speed is low enough to avoid excessive centrifugal forces that could damage the berries or cause them to be flung out of the rollers' grip. Using a higher RPM could increase the risk of berry damage or loss, while a lower RPM would reduce the machine's processing capacity and efficiency.

The rollers rotate inward toward each other, which is critical to the harvester's function. This inward rotation pulls the pepper berries into the narrow gap between the rollers, creating a secure gripping force that holds the berries firmly and guides them smoothly through the machine. If the rollers rotated outward or in the same direction, the berries would likely slip away or be pushed out of the system, leading to loss and inefficient harvesting. The inward motion also prevents jamming and allows a continuous, controlled flow of berries toward further processing stages, such as cutting or threshing.

Sponge wrapped around a 7mm rod is used as the roller because it offers a gentle, flexible surface that grips the delicate pepper berries effectively without causing damage. The 305 RPM speed, measured precisely with a tachometer, ensures an optimal balance between fast processing and safe handling; speeds higher than this risk damaging the berries or losing them from the rollers, while slower speeds decrease harvesting efficiency. The inward rotation of the rollers is essential for pulling the pepper berries into the gap, holding them securely, and guiding them smoothly through the harvester, preventing slippage or ejection and maximizing harvesting efficiency.

4.2.3 Cutting mechanism

4.2.3.1 Silder Crank Mechanism

$$\text{Silder displacement, } x = 2r \cdot \sin(\theta/2)$$

r = 1.6 cm , $\theta = 138^{\circ}$ (These values are manually measured with help of measuring ruler and protractor respectively).

x = 2 *1.6 *(sin (138/2))

x = 3.2 *sin(69)

= 2.99 cm

After solving the equation, where the crank length r is 1.6 cm, we found that the blade displacement is approximately 2.99 cm when the crank angle θ reaches 138 degrees. This angle represents the rotation of the crank required to achieve the desired blade stroke for effective peduncle cutting in the black pepper harvester. The calculated displacement of 2.99 cm indicates that the mechanism operates efficiently, ensuring precise blade movement to cut the peduncle while minimizing the risk of damaging the pepper berries.

4.2.4 Drive mechanism

The pulley connected to the roller in the black pepper harvester rotates at approximately 305 RPM, which was measured using a tachometer. This speed is optimized to ensure the pepper berries are gently gripped and processed without damage. At 305 RPM, the rollers maintain a balance between efficient throughput and careful handling of the delicate berries. The chosen speed ensures that the berries are not subjected to excessive forces, reducing the risk of bruising or slipping while allowing the machine to operate at a practical and effective rate for continuous harvesting.

4.2.5 Power source

The power source for the black pepper harvester is a 9-volt battery, which provides a compact and portable supply of electrical energy to operate the machine's electronic components. This battery offers a stable voltage ideal for powering small DC motors that drive the harvester's mechanical parts. When powered, the DC motor rotates, causing the roller to turn, which helps in gently detaching the pepper berries from the vines. The lightweight and easy-to-connect design of the 9-volt battery makes it convenient for field use, ensuring the harvester remains efficient and user-friendly. Although the battery has limited current capacity, it is sufficient for the low to moderate power requirements of the motor and roller system, enabling effective harvesting without the need for bulky or heavy power units.

4.2.6 Control Unit

4.2.6.1 Arduino Microcontroller

The black pepper harvester employs an Arduino Uno as the control unit, which serves as the central processing system for managing the device's functions. The Arduino Uno's versatility and ease of programming allow for efficient integration of sensors, actuators, and control logic in a compact and cost-effective manner. Its ability to process input signals and generate appropriate control outputs ensures smooth coordination of the harvester's mechanical and electronic subsystems, thereby facilitating semi-automated operation. This platform also enables straightforward modifications and adjustments to control algorithms, supporting iterative design improvements.

4.2.6.2 Servo Motors

For precise blade movement, servo motors are utilized. Servo motors are ideal for applications requiring accurate angular positioning, as they respond quickly to control signals and provide reliable feedback on position. In the black pepper harvester, the servo motor effectively controls the cutting mechanism, ensuring consistent and controlled blade operation during the harvesting process. This precision reduces the risk of damage to the pepper spikes and improves the efficiency of cutting, resulting in a smoother and more reliable harvesting cycle.

4.2.6.3 Pulse Width Modulation (PWM)

To regulate the speed of the DC motor driving the rollers, pulse width modulation (PWM) is implemented. PWM allows for fine-grained speed control by adjusting the duty cycle of the electrical signal supplied to the motor. This method provides an energy-efficient means of varying motor speed, enabling the rollers to adapt to different harvesting conditions and pepper stem sizes. By fine-tuning the roller speed, the system minimizes damage to the pepper spikes while ensuring effective separation from the plant, contributing to the overall performance and precision of the harvester.

4.3 CAD MODEL

4.3.1 Solid Works

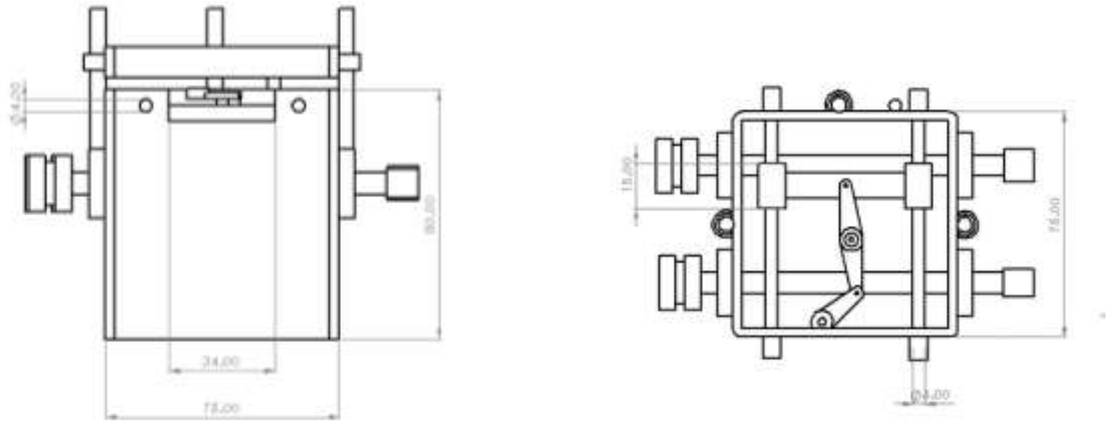

Fig 4.1 Front and Top View

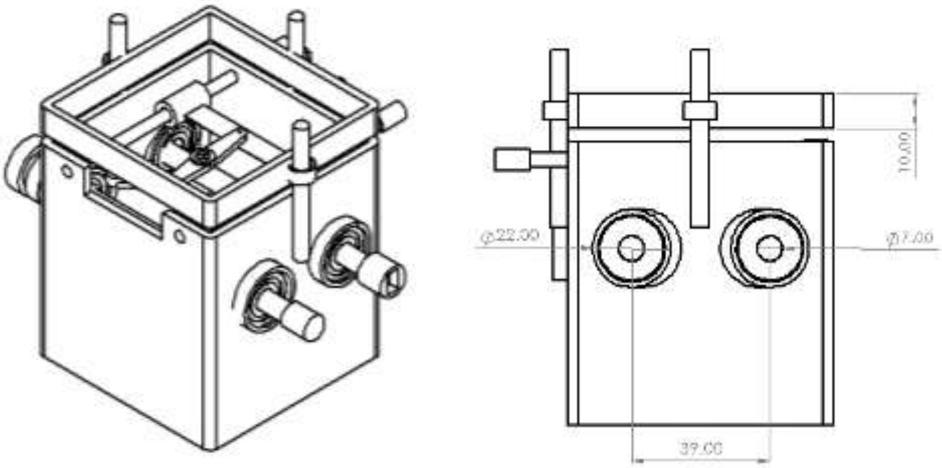

Fig 4.2 Side and Isometric View

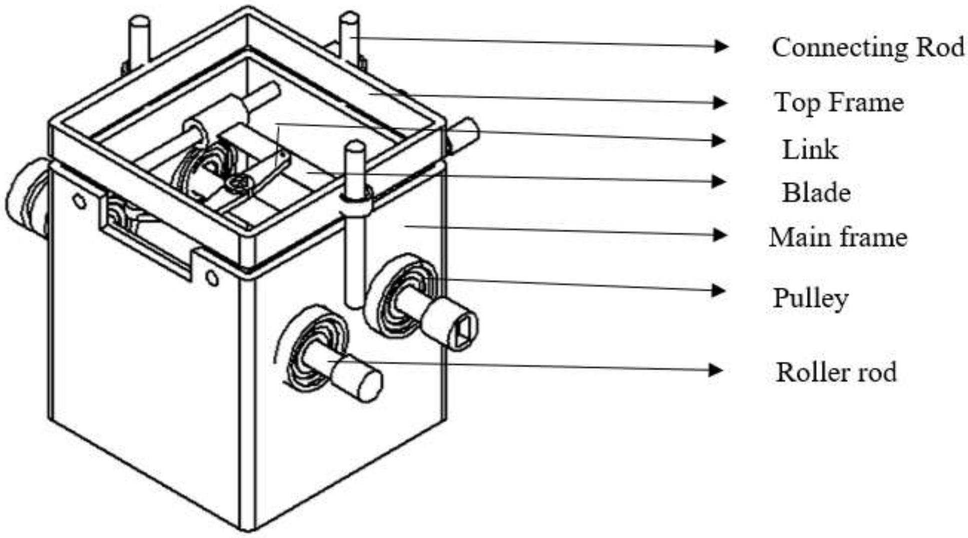

Fig 4.3 Isometric View with parts

4.4 DEVELOPMENT AND FABRICATION PROCESS

4.4.1 3D Printing

The black pepper harvester frame is constructed from Acrylonitrile Butadiene Styrene (ABS)**,** a lightweight and durable thermoplastic that ensures easy handling, portability, and sufficient mechanical strength for field operations. The ABS frame**,** fabricated using 3D printing technology, allows for customization, precise design, and cost-effective production of complex parts, making it an ideal choice for small-scale agricultural tools.

4.4.2 Collecting Method

A mosquito net**,** typically made from polyester mesh fabric**,** is integrated into the design to collect the pepper spikes after cutting. Polyester is selected due to its lightweight nature**,** durability, and tear resistance**,** ensuring that the net can withstand repeated use in outdoor conditions without significant wear. The net's fine mesh prevents the loss of harvested pepper spikes, while allowing airflow to minimize moisture buildup. An aluminium rod is used as a support structure which offers an excellent strength-to-weight ratio, corrosion resistance, and ease of fabrication, making it a reliable component for agricultural equipment. Together, the combination of ABS, polyester netting, and aluminium rod provides a balanced solution for a functional, lightweight, and ergonomic black pepper harvester. For applications requiring greater load-bearing capacity, aluminium or steel may be preferred for the frame due to their superior mechanical properties.

4.5 COST ANALYSIS

Table 4.6 Cost Analysis

Component	Quantity	Unit Cost (INR)	Total Cost (INR)	Remarks
ABS (plastic sheets)	1 sheet	₹830	₹830	For structural parts
Sponge material	0.5 meter	₹166	₹83	Cushioning or padding
Arduino board	1 unit	₹2,075	₹2,075	Microcontroller board
Limit switch	1 unit	₹249	₹249	Position detection
Servo motor	1 unit	₹300	₹300	Actuator for movement
9V Battery	1 unit	₹332	₹332	Power supply
Connecting wire	1 meter	₹125	₹125	Electrical connections
TOTAL COST				₹4,409

SUMMARY AND CONCLUSION

CHAPTER 5
SUMMARY AND CONCLUSION

A semi-automatic black pepper harvester combines the benefits of mechanization with some manual control, making it a practical solution for pepper farmers. It improves harvesting speed compared to fully manual methods, allowing farmers to pick pepper berries more efficiently while still maintaining control over the process. This type of harvester reduces labor requirements and physical strain, especially when harvesting from tall or dense vines. Because it requires less manual effort, it helps increase productivity without completely removing the farmer's involvement, which can be important for delicate handling of the crop. Semi-automatic harvesters are generally more affordable and easier to maintain than fully automatic machines, making them accessible to small and medium-sized farms. Overall, they provide a balanced approach to improving harvest efficiency, reducing labor costs, and preserving crop quality.

5.1 ADVANTAGE

The development of a black pepper harvester involves the integration of mechanical and electronic components designed to improve harvesting efficiency, reduce labor dependency, and ensure timely collection of pepper berries. Before proceeding with the fabrication or implementation of such a device, it is essential to evaluate the overall costs involved. This cost analysis outlines the estimated expenses for key components used in the construction of a basic semi-automatic black pepper harvester. It includes materials such as structural elements, electronic control units, actuators, power sources, and other supporting accessories. Understanding the cost breakdown helps in budget planning, economic feasibility assessment, and potential scaling for commercial applications.

5.2 LIMITATIONS

While the developed black pepper harvester showed promising results in terms of basic functionality and performance, it has several limitations. The tool is not suitable for harvesting pepper spikes located at greater heights, as its design restricts effective reach beyond a certain level. Additionally, the harvester is not ideal for prolonged use in the field, as extended operation may lead to user fatigue due to the manual nature of the mechanism. The materials used for fabrication, such as ABS and sponge, are more appropriate for prototype development and may not withstand long-term usage under real farm conditions. Continuous use over multiple harvesting seasons may result in wear and damage, affecting durability and efficiency. These limitations highlight the need for further refinement and structural enhancement before large-scale field deployment.

The project titled "Development of Black Pepper Harvester" was undertaken with the objective of designing and fabricating a semi-automatic tool to ease the challenges associated with manual black pepper harvesting. This work focused primarily on the mechanical design and development of the harvesting tool, without the implementation of any coding or electronic automation components.

Based on a detailed study of the physical properties of black pepper spikes—such as length, diameter, peduncle size, and berry count—a harvesting mechanism was conceptualized using rollers and a blade system. The selected materials, including ABS for the frame and sponge-covered rollers, ensured gentle handling of pepper spikes while maintaining structural efficiency. The kinematic analysis of the two-bar linkage system validated the feasibility of the cutting mechanism and guided the design parameters for efficient operation.

While the integration of Arduino-based control and motor automation was conceptually addressed, the actual coding, programming, and circuit implementation were not carried out in this phase of the project. Instead, the project successfully achieved the mechanical design and fabrication goals, producing a working prototype suitable for manual or semi-assisted operation. This harvester provides a foundational model that can be further enhanced in future stages by incorporating electronics, sensors, and automation to make it a fully operational, field-ready harvesting solution. The work serves as a stepping stone toward reducing labor dependency and improving ergonomic safety in black pepper cultivation.

Plate 5.1 Black Pepper Harvester with team

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DEVELOPMENT OF BLACK PEPPER HARVESTER

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ABSTRACT

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ABSTRACT

India is one of the leading producers and exporters of black pepper, commonly known as the "King of Spices." However, the harvesting of black pepper remains a labor-intensive, time-consuming, and ergonomically challenging process. Workers are often required to climb vines or use ladders, exposing them to physical strain and health risks such as musculoskeletal disorders. Additionally, manual harvesting contributes to yield loss due to improper handling and collection inefficiencies. Existing mechanical harvesters are often expensive, bulky, and not suited for small or marginal farmers due to lack of ergonomic design and affordability. This project aims to develop a semi-automatic black pepper harvester that is cost-effective, lightweight, ergonomically designed, and efficient. The design process began with a detailed study of the physical and mechanical properties of black pepper, including spike length, diameter, peduncle dimensions, number of berries per spike, and required cutting force. These parameters informed the development of the cutting and gripping mechanisms. The developed harvester uses sponge-covered rollers for gentle gripping of pepper spikes and a slider-crank mechanism driven by a servo motor for precise cutting. A microcontroller-based control system using Arduino Uno enables synchronized operation of the roller and cutting mechanism, with speed modulation through pulse width modulation (PWM). A collection system comprising a mesh bag made of polyester is integrated into the device to gather the harvested spikes, minimizing post-harvest losses and operator effort. Key components such as the structural frame were fabricated using 3D printing technology with ABS material to ensure lightweight and durable construction. The device is powered by a 9V battery, making it portable and suitable for field operations without external power sources. The project concludes that this low-cost, user-friendly device has strong potential for adoption by small and medium-scale farmers, offering a sustainable solution to labor and productivity challenges in black pepper cultivation.