DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF TURMERIC POLISHING MACHINE

Dawud Teha Ahmed

A Thesis Submitted to the Department of Mechanical Engineering, School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirement for the Degree of Master’s of Science in Agricultural Machinery Engineering

Office of Graduate Studies

Adama Science and Technology University

October, 2023

Adama, Ethiopia

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DECLERATION

I hereby declare that this Master Thesis entitled "Design, Development and Performance Evaluation of Turmeric Polishing Machine" is my original work. That is, it has not been submitted for any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Name of student	Signature	Date

Recommendation of Advisor/Supervisor

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "Design, Development and Performance Evaluation of Turmeric Polishing Machine" submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Agricultural Machinery Engineering.

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Name of Advisor	Signature	Date

APPROVAL SHEETS

I, Dr. Amana Wako, the advisor of the thesis entitled “Design, Development and Performance Evaluation of Turmeric Polishing Machine” and developed by Dawud Teha Ahmed; hereby certify that the recommendation and suggestion made by the board of examiners are appropriately incorporated into the final version of the thesis.

Name of Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Dawud Teha Ahmed have read and evaluated the thesis entitled “Design, Development and Performance Evaluation of a Turmeric Polishing Machine” and examined the candidate during the open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Agricultural Machinery Engineering.

Chairperson	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies Dean	Signature	Date

DEDICATION

To my father, Teha Ahmed and my mother who sparked my academic career in all cases and for their love, care and support in prayer.

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ACRONYMS

ASME	American Society of Mechanical Engineers
DWC	Durbin-Watson Coefficient
ECTA	Ethiopian Coffee and Tea Authority
GLM	General Linear Model
GMD	Geometric Mean Diameter
MARC	Melkasa Agricultural Research Center
RCBD	Randomized Complete Block Design
SFE	Strategy for Ethiopia
SNNP	Southern Nation Nationalities and Peoples
TARC	Tepi Agricultural Research Center
TNSRC	Tepi National Spices Research Center
UAE	United Arab Emirates

ABSTRACT

Turmeric (Curcuma longa Linn*), locally known as 'Ird', is the dried rhizome of herbaceous plant grown extensively in tropical and subtropical parts of Ethiopia. It is widely grown in most parts of the country, such as Jimma, Metu, Tepi, Bebeka, Wonago, Awasa, Mugi, Bako, Sheka, Benchmaji, and Kefa. It has a rough, dull outer surface with scales and root crumb, which needs to be polished for higher quality and price. Manual and/or mechanical polishing improves its appearance, resulting in relatively smooth, bright and yellow surfaces. However, the manual processing challenges and the demand for high-quality final products have created a need for the development of turmeric polishing machines. Therefore, this research focused on the design, development and performance evaluation of an engine operated turmeric polishing machine suitable for small holder farmer and small-scale enterprises. The designed machine consists of several components such as engine as power source, speed reducing system, power transmission component parts, octagonal drum as polishing unit and collector. The physical properties of turmeric rhizome used to design and select component parts of the machine were studied with samples procured from farmers. The performance evaluation of the machine was carried out on three levels drum speeds (70, 85, 95 rpm), polishing time (15, 20, 25 min) and three different moisture content (6, 9, 11%) for fixed capacity of 200 kg turmeric in the drum. The results showed that the machine had a polishing capacity of 364 kg/hr. The linear regression analysis was used to determine if the predictor variables could influence the polishing percentage, damage, and fuel consumption during polishing. The likelihood function analysis of linear regression depicted that damage of product during test of turmeric was influenced by all independent variables with* $R^2=0.893$ *and DWC of 0.367 at significance level of* $p<0.001$*. Furthermore, the analysis showed that all predictor variables significantly influenced polishing percentage at significance level of* $P<0.001$*. The polishing percentage increased with increasing speed, longer polishing time and higher moisture content. However, further analysis showed that a slight decline in polishing percentage when the drum speed exceeded 85 rpm, likely due to centrifugation effects within the drum. Additionally, the performance evaluation demonstrated that fuel consumption was directly affected by predictor variables, except for moisture content, with an* R^2 *value of 0.993 and a DWC of 2.530. Based on the performance results, the machine was deemed acceptable and suitable for use by smallholder farmers and small-scale enterprises.*

Keywords*:* Damage, Design, Polishing Machine, Polishing Percentage, Turmeric.

CHAPTER ONE

1. INTRODUCTION

1. 1. Background

Since the time man started gathering food, spices seem to have been used to make the food more appetizing, add aroma and taste to cereal or meat dishes. Turmeric (*Curcuma longa L.*) (Ird) is a dried rhizome of herbaceous commercial spicy crop and native of South Asia. Turmeric, because of its yellow color, was gain attention from the very early days. It is a unique ingredient produced in most parts of the world and used as a spice, colorant, and flavoring and medicinal purposes. The attractive coloring effect, turmeric is used for industrial purpose in garment, textiles and pharmaceutical products (Purseglove *et al.,* 1981; Pruthi, 1998; Girma Hailemichael et al., 2016). It is grown in tropical and subtropical countries viz., Ethiopia, India, Pakistan, Myanmar, Chile, Peru, etc). It was introduced to Ethiopia in the late 1970s by Tepi National Spices Research Center (TNSRC). According to Behailu Mekonnen and Weyessa Garedew (2019), now a days, turmeric is widely grown in the southeast and southwest part of Ethiopia like Jimma, Metu, Tepi, Bebeka, Wonago, Awasa, Mugi, Bako, Sheka, Benchmaji, and Keffa.

Rainfall of 1000 to 2000 mm is favorable range for successful production of turmeric rhizome according most research study conducted agronomic demand during past years. Supplementing with irrigation was also an important practice in case where shortage of annual rainfall exists as it can grow 2000 m above sea level (Anitha and Hore, 2018). Turmeric often needs a hot, humid atmosphere. Additionally, it needs well-prepared, loose, friable loamy or alluvial soil. Turmeric planting sites need to be well-prepared and tilled to provide a loose, friable seedbed. The rhizomes can be used to create three different kinds of planting supplies. These include finger rhizomes (split rhizomes), daughter rhizomes (secondary rhizomes), and mother rhizomes (arises from the original planting material). Growing turmeric via inter-cropping with other horticultural crops including banana, coffee, and enset was prevalent in the southwest and western regions of Ethiopia (Girma Hailemichael et al., 2008). In comparison to the usage of ridges and/or raised beds in ginger, planting on flat terrain had produced the maximum rhizome output. The harvestable stage of turmeric takes 8 to 9 months

However, fresh rhizome yield of turmeric was highly enhanced by planting on raised beds (34 t/ha) under Tepi conditions (Tsegaye Shime, 2021). However, turmeric harvesting commences in early March, thus planting could be carried out in mid of June (Girma Hailemichael et al., 2016). It is a nine-month crop sown in early July and harvested in April (Jaggi, 2012).

With the leading producer of turmeric, India was the consumer and exporter of turmeric accounted 88,728 tons of turmeric out of 967,860tons of production during 2017-18 (Poornima et al., 2019). It accounts approximately 83% of the world turmeric production followed by China, Myanmar and Bangladesh respectively. The major countries which import Indian turmeric are UAE, Bangladesh, Malaysia, Iran, UK and United States of America (Poornima et al., 2019). Ethiopia`s favorable and encouraging geographical and environmental conditions for various spices production due to the presence of agro-ecology, climatic conditions and abundant cultivable land with possibility of irrigation potential and government policy direction is more promising for more production of turmeric rhizome (Hordofa & Tolossa, 2020).

However, because of ginger bacterial wilt and high demand for turmeric, major ginger-producing zonal areas, like the Wolayta zone, have currently shifted their land agricultural practice to turmeric production. Most of Ethiopia's population is featuring experienced meat-free and vegan dishes over centuries because of its use in the preparation of food for enhancing the flavor and aroma, adding piquancy and improving appearance by adding color to food that extended to Eritrea (Peethambaran et al., 2016). Turmeric is one of the most flavored products by Ethiopian homemakers as main ingredients of the local sauce called alicha wot (Behailu Mekonnen and Weyessa Garedew, 2019). As a result, most of the turmeric produced in Ethiopia is consumed domestically, while the other portion is exported to countries like Djibouti, Egypt, Sudan, Yemen, Tanzania, Kenya, Morocco, Saudi Arabia, India, Europe, China, and USA (Roukens et al., 2005; Vishwabhushan, 2016).

It is one of exported spice in Ethiopia, as a cash crop and many livelihoods had been depending on it for a living (Habetewold Kifelew et al., 2018). According to Habetewold Kifelew et al., (2018), India imported turmeric worth USD 4,635,094 from Ethiopia in the past years. According to Ethiopian Coffee and Tea Authority (2020), turmeric is exported to more than 28 countries with India the highest importer of Ethiopian Turmeric rhizome (Appendix E). Turmeric accounts for 8% (USD 2.1 million) of the 2013 total spices export in Ethiopia (Herms, 2015). About 76% of Ethiopia's turmeric production is covered in SNNP with a production of 22.75 tons in the 2013/2014 year (Peethambaran et al., 2016). The average production of turmeric in the last five years from 2018 to 2022 was 24057.3tons with a higher production of 27,125 ton in 2022 (ECTA). Turmeric production in the country is increasing in the past five years with dramatic increase of demand in production and consumption in the country (appendix E). Turmeric as spices enables Ethiopia to earn foreign exchange and adds value to the national economic growth. According to the data from Ethiopian Coffee and Tea Authority (ECTA) in 2021 G.C indicates, an average of 3775.03 tons in five years turmeric was exported nearly to 27 countries of the world. India, Yemen, Jordan, Saudi Arabia, Djibouti, UAE and Vietnam were the major importer of turmeric product from Ethiopia.

Accordingly, an increasing number of turmeric market participants attractive to operate in Ethiopia (Ethiopian Investment Commision, 2015). This was beneficial because Ethiopia was the largest producer and exporter of turmeric in Africa (Chaudhary et al., 2006). However, despite Ethiopia's long history of spice cultivation and marketing and its favorable agro-ecology for spice production, the country's position of spice production and export is often below expectations (Tsegaye Shimelis, 2021). But now days because of favorable environment of government policy direction and support it strategically planned to increase the spice production including turmeric.

For marketing turmeric rhizomes were valued for its cleanness and polishing form of products. Dried turmeric has a poor appearance and a rough dull outer surface with the scale and root bits. There are difficulties on farmers to remove this scale and root bits from turmeric manual practice (Girma et al., 2016). Instead of boiling and polishing most farmers are selling fresh fingers after washing and cutting it longitudinally (Vishwabhushan, 2016). They commonly bypass the polishing step of the turmeric process (Girma et al., 2016). At present majority of the farmers are using traditional processing equipment barrel which exposes processors to the difficulty of fumes during processing, more water, and fuel requirements, the difficulty of handling during a take in and out rhizomes as well as to long exposure of processors to heat during boiling and taking out rhizomes (Nasri, 2014). In addition to, the poor handling of boiled rhizomes results in loss, products mud mixing, scorching, and trampling, which reduces both the quality and quantity were among the major loss of the product after harvesting it. Most households sell the produced turmeric to market without polishing. It was manually polished in home for home use. Besides its economic benefit for smallholder farmers' income it was sold by low prices to brokers and merchants. This indirectly resulted in low production rate of turmeric despite its high economic benefit for national GDP. In most parts of production area turmeric was produced and stored without drying, which leads to high loss of product. This was nothing but because of absence small scale turmeric polishing machine. Turmeric polishing is an essential issue to activate the producer's quality handling, quality polishing and enabling national economic share of turmeric product as spices and more production in the future.

1.2. Statement of the Problem

Turmeric is a root crop that is exported and generates income for Ethiopia in the past decades in addition to its use in the preparation of food for enhancing the flavor and aroma, adding piquancy and improving appearance. In-spite of its contribution to the national economy, through import and export, improved post-harvest handling and processing technologies are still lacking for turmeric. the major processing steps to attain yellow-orange turmeric pass through the steps such as boiling, drying, and polishing. Among these steps polishing was more challenging and laborious. It was women, who were engaged for processing turmeric after harvesting. They almost practice traditional ways for processing turmeric. Challenges of preparing quality turmeric product because of traditional ways of polishing and absence of appropriate technology used for polishing on small scale worsen polishing.

In fact, polishing ensures quality of turmeric rhizome with minimized loss. High quality turmeric gives higher income in the market and more preferred for export. On the other side, farmers avoid polishing step in the process, which are the most basic and key procedure to ensure quality of the product or sell raw unpolished turmeric to commercial polishers with 75% less prices of polished turmeric. Despite number of studies carried out on property and extensive use of turmeric there was no turmeric polisher developed in the country for small scale uses. Additionally, while extensive processing technologies were developed in the research centers there was no research study aimed to solve the above problems for insuring supply of quality product for local and international market with the benefit of small holder farmer and small scale entrepreneurs. Thus, it was deemed worthy for the study to develop polishing machine which has been found to be the preeminent option to solve existing challenges by designing and developing appropriate technology for the existing challenges.

1.3. Objectives of the Study

1.3.1. General objective

The general objective of this research is to design, fabricate, and undertake performance evaluation of engine operated turmeric polishing machine.

1.3.2. Specific objectives

- ✓ To study the physical and mechanical properties of turmeric rhizome.
- ✓ To design and fabricate turmeric polishing machine component parts.
- ✓ To test and evaluate the performance of turmeric polishing machine.

1.4. Significance of the Study

The output of this study would be particularly for the benefit of stallholder farmers and small scale enterprises with supply of quality turmeric to market and reduced drudgery in polishing. Polishing turmeric by this machine enables added value to the product, preferred on preparing turmeric for the market. This study therefore, contributes to the efforts of preparing quality product for the market. Working towards attaining socio-economically desirable use of turmeric, experiencing its deep yellow and foreign currency exchange the aim is to design and develop engine operated polisher to reduce loss of quality product prepared for local use and/or for market. It also reduces dependence on the traditional polishing methods done by human hand. The turmeric processing involves boiling the fresh rhizomes in water, drying in the sun and finally polishing. This machine is not in use for washing. Instead of polishing some farmers are exporting fresh fingers after washing and cutting it longitudinally.

Thus, the development of this polisher reduces unpolished product prepared for the market, enhancing quality of product then higher price. Therefore, this machine replaces farmer's conventional method of turmeric polishing experienced manually, which was labor-intensive, tedious, and very slow form of polishing. Designed turmeric polisher had extra advantage like ease of labor saving and faster production rate, improved quality work, and requirement in limited experience during operation. Finally, availability of polishers is the best solution to lack of uniformity of the final product among farmers, saving time, labor and fitting to agro-ecology of the country.

1.5. Scope of the Study

This research specifically focuses on the design and development of polishing machine by designing component parts and fabrication of its prototype before performance testing and evaluation. It includes the processes those needs to design and construct the efficient turmeric polishing machine. As of this study, the development of engine operated turmeric polishing machine is intended to be the solution for polishing problems faced by turmeric producer farmers in Ethiopia. The study does not consider industrial scale design purposes rather it considers farmers, entrepreneurs and small-scale enterprises. The machine polishes the dried turmeric product but does not wash or dry by itself. In design process the quality of polishing, labor saving, suitability, easiness of technological property and availability was also considered during development.

1.6. Organization of the study

The research is organized into five major chapters. Chapter one describes the introductory part, which contains the background of the study, statement of the problem, objectives, and scope of the study. Chapter two illustrates the review of literature, containing the theoretical and empirical literature of past research fellows. In Chapter 3, the methodologies followed and used were discussed in detail. Chapter four presents the research results and discussions of the study. Finally, conclusions and recommendations were discussed in Chapter 5.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Morphology of Turmeric Rhizome

According to Yewle et al. (2019), turmeric is a rhizomatous perennial herb with primary and secondary rhizomes that can appear in a variety of shapes, including cylindrical, spherical to slightly conical, and hemispherical. The rhizomes have an orange-yellow meat covered by a thin peridermis layer of somewhat brown peel (Balasubramanian et al., 2012). The plant has a short stem and can grow up to 1 m tall.

Figure 2.1. Turmeric rhizome

2.2. Turmeric Rhizome Harvesting

Turmeric is usually harvested nine months after planting if the product is for local use. When oleoresin extraction needed it is harvested after seven months. Oleoresin is a mineral content of turmeric for medical use. The plants were harvested when leaves had dried (Amadi et al., 2015). Usually farmers harvest the crop when the leaves start drying and the field has a typical pleasant smell of turmeric. For processing, harvested turmeric is washed thoroughly to remove soil particles.

2.3. Turmeric Pre-polishing Process

2.3.1. Turmeric washing

Fresh rhizomes need to be cleaned of dirt, plant pieces, and soil that is adhered to roots etc. Niranjan (2013), suggests that pressure washing will be better if it is available and easily to access. After washing the mother and finger rhizomes are grouped in to different lots before further processing. Lack of awareness on washing and storage management are an important factor affecting the quality of turmeric in the export chain that helps gain higher price (Hordofa & Tolosa, 2020).

2.3.2. Turmeric boiling

Boiling turmeric rhizome was valuable for the attainment of both color and aroma after harvest. The traditional technique of curing turmeric rhizomes is to boil fresh product for almost 45-60 minutes in a barrel or other material with continues fire (Girma Hailemichael et al., 2008). According to Poornima et al., (2019), the rhizome should be washed and cleaned from foreign materials and remove dirty substances adhering to the rhizomes before boiling. The purpose of 'boiling' is to remove the raw odor, reduce the drying time, gelatinize the starch and produce a more uniformly-colored final product (Pruthi, 1998; Girma Hailemichael et al., 2008).

Turmeric producers in southwest Ethiopia typically cure their products on the farm. Fresh rhizomes are boiled in water and then dried in the sun to cure turmeric (Gitanjali et al., 2014). The turmeric rhizome's microbial load is greatly reduced throughout the curing process by boiling the rhizomes (Pratik & Shrikant, 2015). Over boiling spoils, the color of the final product while under boiling makes the dried product brittle. As the boiling duration increase, the loss of curcumin and oleoresin contents increased (Raza et al., 2018) with the need of optimum level boiling. The best curing time of turmeric (25 minutes) yields high quality regardless of loss, fuels expenditure, water and time as studied in 2017/2018 using improved turmeric boiler at Tepi Agricultural Research Center (TARC).

2.3.3. Drying turmeric rhizomes

Drying is the most important method of preservation to quality and prolongs storage life (Ratti and Mujumdar, 1996). The processing of cutting/slicing of turmeric is necessary to achieve fast and uniform drying for the preparation of turmeric slice (Murumkar et al., 2016). Traditionally the cured rhizomes were spread on the ground in the sun to dry and this process takes up to 15 days. According to Moghe et al., (2012), turmeric needs to be sliced aor dried before 48 hours after harvesting or boiling to avoid loss in its nutrient values and shrinkage. Today the majority of internationally-traded turmeric rhizomes are artificially dried with hot-air drums, tray and continuous tunnel driers. Farmers in Ethiopia dry their turmeric in an open air by spreading on the ground (Lamrot W/Mariam, 2017).

Rhizomes to be dried can be sliced or whole dried, with slicing commonly producing a more uniform and brightly colored powder (Pruthi, 1998; Lima et al., 2017). But, the loss was high with respect to other pre-polishing processes. The final moisture content should be close to 6-15% (Borah, 2015). Shrinkage is another physical phenomenon which occurs during drying on most of the biological materials, especially in products having higher moisture content like turmeric. The finger rhizomes recorded 50.54%, 27.38% and 76.80% average reduction in thickness, length, and volume respectively when the moisture content is reduced from 70-80% to 7.80% (d.b) that requires long period treatment to dry (Biruk Hirko, 2018).

2.3.4. Turmeric polishing

Turmeric polishing post-drying operation carried out after drying the rhizome followed by cleaning, boiling. Dried turmeric rhizome has a rough dull outer surface with scales and root crumb. Smoothing and polishing the outer surface by manual or mechanical rubbing improve the appearance (Reshma & Vishwanath, 2020). Dried turmeric polishing is to remove the outer dirty skin, roots, and soil particles and transformed into relatively smooth, bright and yellow surfaces (Moghe and Zakiuddin, 2013). Polishing of dried turmeric has number of problems because of high quality need in final product (Girma Hailemichael et al., 2008; Moghe, 2012; Hoque and Hossain, 2018). Manual polishing consists of rubbing the dried turmeric surface with sacks or covering by clothes.

The mechanical processes could use powered drums or conventional barrel drums that are operated by hand. Rhizomes are rotated, and polishing happens when rolling rhizomes abrade the drum's inner surface. The friction created by the turmeric rhizome rubbing against the rough surface during polishing has an impact on the physical and mechanical qualities of turmeric. Typically, full and partial polishing of turmeric rhizome results in weight reductions of 5 to 8% and 2 to 3%, respectively (Yewle et al., 2019). The importing regions impose quality requirements, which are more concerned with hygiene than spice quality. Hereby, researchers in other countries had put their effort into developing improved turmeric processing machines and they classified into several ways based on the source of power and operational mechanism. Bhongirwar et al., (1994) reported that the power operated continuous ripened/raw slicer that was the most common slicers available now are the power-operated slicers. The machine cuts the turmeric rhizomes into slices of desired thickness (1.5 to 5mm) (Murumkar et al., 2016). Fantahun and Teklu (1995), cited in Girma Hailemichael et al., (2008) also discussed the traditional processing carried out by growers are the main factors for the inferior quality of spice products in the export market. Turmeric contains moisture, which should be reduced to a safe limit for milling (10%), and storage (6%) (Singh et al., 2010). Polished fingers yield a better price (SFE, 2010). Moreover, the availability of mechanical turmeric processing technologies is low in the market and very costly to the limit of small entrepreneurs and a serious gap in the demonstration and popularization of available technologies of these valuable crops for economic significance (Girma et al., 2016). For this reason, some entrepreneurs' and smallholder turmeric producers used size reduction hand-tools like hand knives and stationary curing units. However, this equipment poses danger to the operator's finger by inflicting the injury, produces the non-uniform product in terms of size, shape, thickness and also produces poor end quality after processing.

2.4. Worthiness of Polishing

Turmeric is mostly used in our daily life. It is the unique source of various types of chemical compounds, which are responsible for a variety of activities and essential spices in the world. It is used in various sectors like cosmetics, diet preparation, food processing and medical purposes (Fulzele, 2021). Apart from the uses as spice, it is used as traditional medicine in Asian countries such as India, Bangladesh and Pakistan. Turmeric should be presented in clean, smooth and bright colour in market for higher prices (Marsha Yimer, 2010). In nature is grown in the soil having different unwanted roots, soil particles, and rough skin. The turmeric rhizome mostly has irregular shapes and sizes; pretreatment such as peeling has proved to cause damage to the sample and caused wastage (Silva & Jayatissa, 2017). Thus, it has to be dried and polished for low damage and to attract customers. According to Yewle et al (2019) polished turmeric rhizome has an average of two fold prices than unpolished one.

Polishing additionally increases the quality of the turmeric rhizome and decreases the spread of soil born bacteria and other diseases. Overall, it has been concluded that polished rhizomes exhibited good nutritional composition than fresh rhizomes.

Figure 2.1.Turmeric rhizome fresh powder

2.4. Turmeric Polishing Methods

With most time-consuming and tedious process was the turmeric prepared for market in our country. It is historically made and delivered to the market in Ethiopia traditionally. After being collected or harvested, the rhizomes are prepared for the market in a boiled and dried form. The gathered rhizomes are boiled in hot water as part of the curing (boiling) process, and then dried in the sun. Most of the households use turmeric for house consumption after washing and pouring it into the water and then mill traditionally (Tsegaye Melese and Nigus Gurmis, 2022). The process of polishing turmeric is essential practice for better income by supplying quality product to the users' preference. The rare options available were employing a manually driven polishing drum or a wooden mortar and pestle to produce such high-quality produce. The process of polishing turmeric with a mortar and pestle was arduous, time-consuming, and prone to breaking the dried and cured products

2.4.1 Manual polishing methods

Manual polishing with the use of hand or legs to remove dirty material coated on the turmeric outer part was performed by farmers. Polishing manually was also performed with rubbing turmeric rhizome by hand. The other method is rubbing with legs by putting the turmeric into sacks if small quantity is needed. If large quantity is needed they use decorticator as another option to polish turmeric crop. The following is captured from literature which is better method of manual polishing than in our country (Hoque & Hossain, 2018).

a)  b)

Figure 2.2. Manual polishing (a. Hand-operated, b. Paddle-operated)

2.5. Mechanical Turmeric Polishing Machines

Dried rhizomes smoothing and polishing on outer surface by manual or mechanical rubbing polishing drum rotates were employed to get processed quality product (Reshma & Vishwanath, 2020). Hoque & Hossain (2018) had developed a polisher operated by 0.37KW electric motor hexagonal drum polishing machine. The critical speed at which the machine operates was 30 rpm with a polishing capacity of 30kg per batch. The polisher is performed to operate to work for 30 minute at which the turmeric develops saturated yellow color (Hoque and Hossain, 2018). This was done to polisher 90 kg turmeric at 85 min. Finally the capacity of the polisher is 63.53 kg/hr.

Figure 2.3. Pictorial view of the polisher

Moghe et al., (2012), developed and evaluated turmeric polisher with polishing capacity of 50kg per batch. This is the time the polisher brought desirable olive yellow surface color and become smooth. According to Moghe et al., (2012), the developed machine took 20 minutes to polish on batch of 50kg turmeric in the polisher to achieve eight percent polishing. The field performance data again shows 8% polishing of 100 kg of turmeric operated for 60 minutes.

Figure 2.4. Pictorial view turmeric polishing machine (Moghe, 2012)

According to Powar et al., (2015) a turmeric polisher evaluated which was operated by 35 hp tractor and 5 hp electricity was made with hexagonal metallic drum and the efficiency was satisfactory. As of Pal et al., (2008) a pedal operated hexagonal polishing turmeric polishing drum was developed for turmeric processing. In Ethiopia mechanical polisher, which is comfortable with our agro ecological and geographical situation is not available.

2.6. Critical Speed of Polishing

The speed at which centrifuging began to occur while the turmeric rhizome was rotating inside the drum is referred to as the critical speed. The polisher should run at a slower pace than this essential speed. If not, the turmeric rhizomes shouldn't be polished properly. The polisher's critical speed was established. Critical speed of the polisher was determined as (Pal et al., 2008; Hoque & Saha, 2017).

$$N_c = \frac{30}{\pi}\sqrt{\left(\frac{g}{R-r}\right)} \quad \ldots\ldots\ldots\ldots \quad (1)$$

Where: N_C =is critical Speed (rpm)

g = gravitational acceleration (m/s^2)

R = radius of the drum (m)

r = radius of turmeric rhizome (m)

As it was noted by Hoque and Hossain (2018) that the radius of the irregular drum was taken as the average radius of circumscribing and inscribing circles of the octagonal drum. As it very small compared to the value of R, r is assumed to be zero in computing the critical speed of the drum. According to Kalra et al., 2013, for proper string, design, the critical speed was taken as 60-80% of Nc.

2.7. Physical Property of Turmeric Rhizome

The physical properties of dried turmeric of the available selected varieties were recorded. The properties are selected on consideration of turmeric polishing machine design and available review of literature. Physical properties are useful in handling, separation, processing and polishing of turmeric rhizomes. Mechanical properties of turmeric are useful in size reduction and conveying operations. The designing process of turmeric polisher starts from determining the properties of turmeric rhizome. Its physical and mechanical properties were important factors for the design of polishing machine. The design of equipment for harvesting, separating, cleaning, handling and storing of any agricultural commodity is influenced by its physical and mechanical properties (Shelake et al., 2018).

2.7.1. Turmeric rhizome dimension and size distribution

The sizes of irregular particles are specified in an arbitrary way. Thus, it is important for design of polisher parts for effective handling. For regular particles, it was easily calculated despite difficulty in irregular shapes. The dimensional characteristics of turmeric rhizome were mostly by the transverse diameters and/or slight lengths on two ends. For this reason in order to increase trials on dimensional measurement of geometric mean diameter. Therefore, the rhizome size was determined by picking a hundred rhizomes randomly and measuring their three principal dimensions, namely length (L), width (W) and thickness (T) using Varner caliper 0.2 mm least count as described below by (Parveen et al., 2013). The principal dimension of turmeric rhizome at given moisture content are expressed by length and diameter and breadth which can be measured by Varner caliper. Sample of 100 turmeric rhizome length thickness were taken and geometric mean diameters of turmeric rhizomes was measured and average mean of the data were taken.

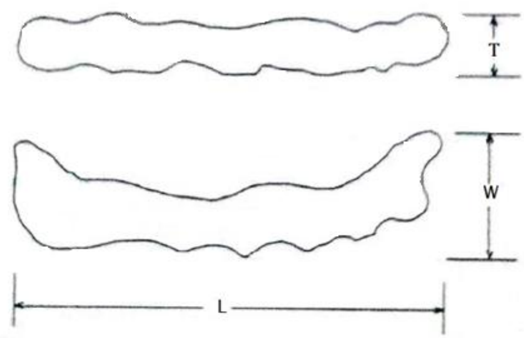


Figure 2.5. Turmeric Rhizome dimensions

The physical property of agricultural product formed because of the angle between base and cone formed by product on flat surface by vertical fall is repose angle. This important property of the material is used in designing of machine storage, processing, and conveying systems (Dhineshkumar & Anandakumar, 2016). Some of the varieties have different physical properties such as length, moisture content, thickness (Habtewold et al., 2018) and affect design performance of polisher. According to the study revealed by Habtewold et al., (2018) the length and width of selected popular varieties are completely different ranging from (2.50 - 3.2 cm) width up to (3.9 - 4.6 cm) in length.

As the findings showed by Shelake et al., (2018) indicated that porosity, bulk density, true density, angle of repose and coefficient of friction were 58.57%, 563 kg/m^3, 1359 kg/m^3, 37.42^0, 0.27 respectively at 10% moisture on dry bases. It was also indicated that as the moisture content decreases, porosity, true density, angle of repose and bulk density decreases. The bulk density, true density and porosity of turmeric rhizome at 12% moisture content were 647.5 kg/m3 and 1303.3 kg/m3, 67.3% respectively (Subhashini et al., 2015). The angle of repose increased from 36.58 to 44.26º in the moisture range of 8 to 16% (w.b). Poornima et al., (2019) found bulk density and porosity to be 640.8 kg/m^3, 47.04% respectively under dried conditions. Balasubramanian et al., (2012) had described number of physical and mechanical property on different grades of turmeric rhizomes. They found that geometric mean diameter, sphericity, bulk desnity, true density, porosity, angle of repose as 12.77, 0.42, 348 kg/m3, 1354 kg/m3, 74.53%, 37.57^0 respectively and coefficient of friction as 0.81, 0.94, 0.86 on aluminum, Mild steel, and plywood sheet. Yewle et al., (2019) discussed turmeric rhizome physical property and mechanical property extensively. He found sphericity, surface area, bulk density, true density, porosity and angle of repose 44.72, 2429.93 mm^2, 663.13 kg/m^3, 1658

kg/m^3, 99.34%, 31.21^0 respectively and coefficient of friction on plywood sheet, mild steel and aluminum as 0.86, 0.95, and 0.89 in order. Barnwal et al., (2014) determined number of turmeric rhizome properties on different moisture content and product sample.

2.8. Research Gap Analysis

Among the processing of turmeric rhizome, polishing was one of the most important steps to reduce loss and enhance quality of turmeric rhizome. Besides, its demand for consumption, medicine, industrial and export for foreign currency earning, polishing of turmeric rhizome was lacking in Ethiopia. Different studies show that turmeric polishing improve quality, shelf life and more expensive than unpolished turmeric. Turmeric polishing can be done by manual, traditional and mechanical machine with changing efficiency.

Moghe et al., (2012) developed circular drum turmeric polisher with polishing capacity of 50 kg/hr with drum speed of 65 rpm at 11% moisture content. The drum does not polish on speed more than 75 rpm despite its lower capacity. In addition to this, the polisher was mainly developed for washing fresh turmeric rather than polishing. As contamination is major problem in food processing, the major limitation was polishing with corroded parts after washing. Polishing machine developed by Hoque & Hossein (2018), with a polishing capacity of 63.53 kg/hr was operating at drum speed of 27 rpm for 25 min and 11-12% moisture content. The polisher developed by these authors was required to operate on relatively higher moisture content resulting to higher loss. Cleaning is a major problem during polishing which needs to separate the waste and unwanted foreign material from turmeric product. Other problem of this major was cleaning efficiency and easiness. Additionally it operates on lower speed meaning lower capacity. Shweta et al., (2022) developed turmeric polisher with a capacity of 30 kg/hr a drum speed of 60 rpm for small scale processing. It was allowed to operate on lower speed and small feeding capacity and it is not economical.

In the past, polisher machines that were created had limited capacity, operated at low drum speeds, and were primarily tested on materials with higher moisture content. In this research study, thus, we employ various parameters and analytical techniques to assess the effectiveness of the newly developed prototype. Critical factors under consideration include drum speed, capacity, moisture content, and operational duration. Additionally, in the design of the polishing unit, the concept of pre-cleaning was introduced to reduce the time needed for cleaning polished turmeric rhizomes. The drum was also equipped with a mixer to ensure uniform polishing of the product within the drum.

CHAPTER THREE

3. MATERIAL AND METHODS

3.1. Description of the Study Area

The fabrication of the prototype was undertaken in Melkasa Agricultural Research Center (MARC). Melkasa Agricultural Research Center was geographically located at 8° 24' 0'' N latitude and 39° 20' 0'' E longitude in the central valley of Ethiopia around 117 km east of Addis Ababa and found at an altitude of 1466 m above sea level. The developed prototype was first tested in Melkasa Agricultural Research Center workshop. After minor modification and approval the batch test for performance evaluation was undertaken at Tepi Agricultural Research Center. Tepi Agricultural Research center was located at 70° 10' N latitude and 350° 25' E longitudes 611 km from Addis Ababa in Southern region of Ethiopia.

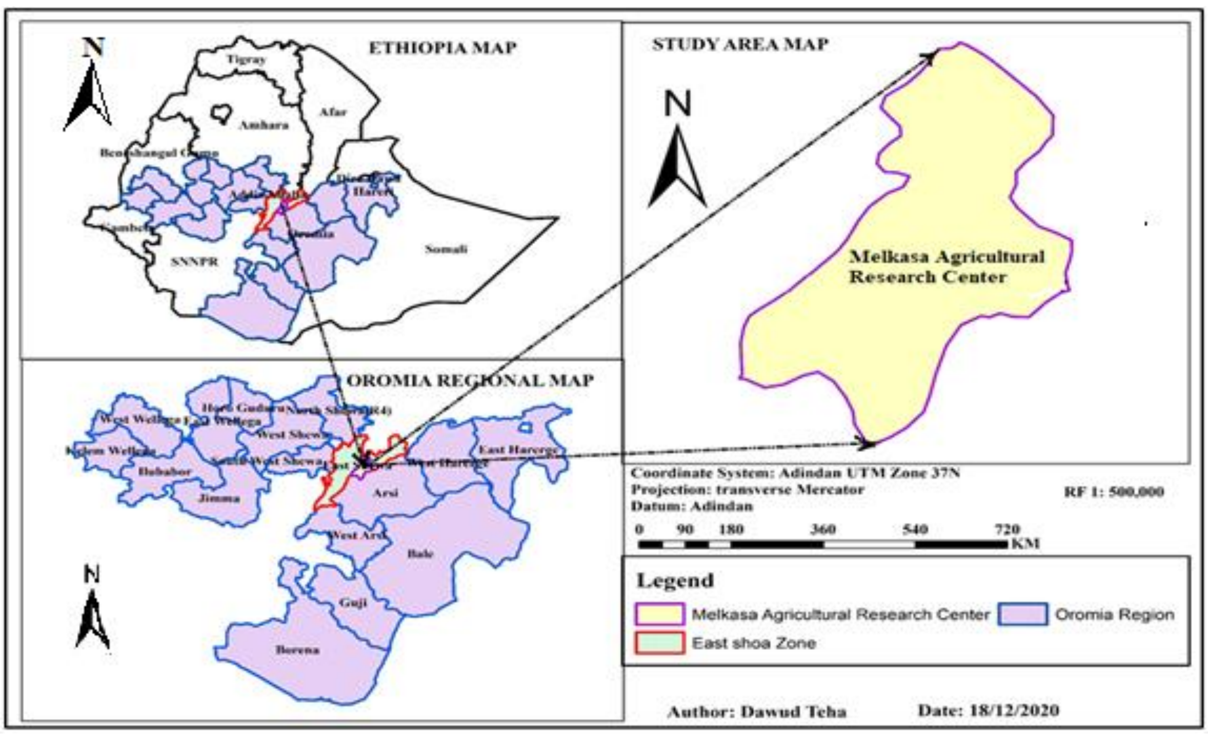


Figure 3.1. Geographical representation of the study area

3.2. Materials

3.2.1. Equipment used for polisher construction

Different machines and tools are used for polisher construction. Each equipment`s use and purpose of use is detailed in the table 3.1 below.

Table 3. 1. Tools and equipment used for turmeric polishing machine manufacturing

No	Machine/tool name	Use
1.	Drill machine	Making hole
2.	Lathe machine	Threading /finishing
3.	Digital Balance	To measure weight
4.	Welding machine	To weld
5.	Varner calipers	Diameter measurement
6.	Screwdriver	Tightening the screw
7.	Spanner	Tightening
8.	Snip	Cutting
9.	File	Smoothing
10.	CNC machine	material bending
11.	Divider	angle measurement
12.	Grinder	Smoothing sides and edges
13.	Cutter	For larger size material Cutting
14.	Measuring tape	To Measure linear distances
15.	Puncher	To perforate sheet metal
16.	Smart Phone	To record operation time

3.2.1. Polishing machine component materials

A rotating octagonal drum was made to enhance polishing percentage and maximize the efficiency of the machine. Design main component parts and selection of material was the major process in developing turmeric polishing machine. The materials used were listed in the table 3.2. Material selection was in accordance with safety from corrosion, strength, availability and costs.

Table 3. 2. Materials used in development of polishing machine

No.	Materials	Quantity	Specification
1	Angle Iron	4	50x50mmx6000mm angle iron for frames and 30x3mmx80mm for slider
2	Sheet metal	3 Pcs	3mm thickness mild steel, 2mm thickness, 1mm thickness SS sheet metals
3	Wire mesh	2pcs	2440mm x 1100mm (4mm x 4mm opening)
4	Expanded metal (Reti)	2 Pcs	2440mmx1100mm (25mmx25mm opening)
	Flat iron	3	5mmx50mmx6000mm
5	Shaft	1Pcs	MS Steel 1700mm length diameter of 45mm
6	Pulley	6pcs	100mm, 70mm, 140mm, 240mm,200mm, 300mm
7	Bearing	2PCs	PS09 (Chromium alloy steel)
8	Electrode	2 pack	ϕ3.2 (used for welding machine parts)
9	Anti-Rust	1kg	To prevent corrosion
10	Paint	1 gallon	To make machine attractive
11	Speed reducer	1pcs	50:1 gear ratio speed reducer
12	Bolt and Nuts	2 types	M10x80, M8x10, M20x40, M19x50
12	5hp diesel engine	1	Power source

3.3. Methods

3.3.1. Determination of machine weight

The total weight of the drum is the sum of component weight of each part the drum is made up of. It was calculated by summing up all components and described as follows. Materials used for construction of the drum were ball bearing, bolts, nuts, perforated stainless steel sheet metal, circular shaft, wire mesh, and expanded metal wire, speed reducer gearbox, Engine, engine seat, drum cover, shaft attachment, Bolts and nuts, Rivets, Sheet metal, Frame, Pulley, Belts, sliding collector.

Therefore the total mass of the machine drum is 117.515 kg. Its weight was determined by equation (2) as follows.

$W = m \times g$ ………………………………………………………………………… (2)

Where: W = the weight of the machine, N m = total mass of the machine, kg

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

$W = 117.515 kg \times 9.81\ m/s^2$

$= 1,152.82\ N$

3.3.2. Source of experimental material for turmeric rhizome

To examine turmeric rhizome characteristics, samples of dominant and popular turmeric variety grown in Ethiopia were gained from Tepi Research Center. To make performance evaluation, 1800 kg was taken from Tepi Research center which was available previously in warehouse and the left amount were procured from farmers at Tepi area during 2023.

3.3.3. Determination of physical properties of turmeric rhizomes

In order to determine the physical characteristics of turmeric rhizome, 100 samples, free from any damages of popular varieties were selected. Dimension of turmeric rhizome at given moisture content were expressed by length and diameter and breadth and measured by Varner caliper.

3.3.3.1. Geometric mean diameter

It was measured by more precise measuring instrument called calipers. Those measurements used as length, width, and thickness respectively. Sample of 100 turmeric produce was taken for measurement of length and geometric mean diameters of the rhizomes. Average mean of the data was taken to describe geometric mean of the rhizome. According to Dilip et al. (2021) the geometric mean diameter is calculated by (Eqn. 3)

$$GMD = (a \times b \times c)^{1/3} \quad \ldots\ldots (3)$$

Where: GMD = geometric mean diameter

a = length of the rhizome (mm)

b = width of the rhizome (mm)

c = thickness of the rhizome (mm)

3.3.3.2. Weight of turmeric

Weight of the rhizome is determined by using digital balance to measure mass and converted it to weight. This is a useful parameter that closely related to volume and size of the rhizome.

3.3.3.3. Surface area and volume of turmeric rhizome

The surface area (S) and volume (V) of Turmeric Rhizome was calculated based on the geometric mean diameter (GMD) according to Dhineshkumar & Anandakumar, (2016). A dried rhizome tends to shrink after drying that decreases the volume of the rhizome. Therefore, the volume was calculated from the sample dried and determined by using (Eqn. 4 and 5).

$$V = \pi(\mathrm{GMD})^2 \quad (4)$$

Where: V = Volume of product (m^3)

GMD = Geometric mean diameter (m)

$$V = 0.25\left[\left(\frac{\pi}{6}\right) l(a+b)^2\right] \quad (5)$$

Where: l = length of the rhizome

a = width of the rhizome

b = height of the rhizome

According to Poornima et al., (2019), surface area of turmeric rhizome is calculated by Eqn. (6)

$$s = \frac{\pi B l^2}{2l - B} \quad (6)$$

Where: $B = \sqrt{ab}$

L= Length

a =breadth

b =thickness

A dried rhizome tends to shrink after drying, enabling decrease of turmeric volume. Therefore, the volume and surface area were calculated from the sample polished and determined by using (Eqn.5 and 6), (Dhineshkumar & Anandakumar, 2016). The length of the rhizome was measured along the two ends of turmeric. Width and thickness were measured across-sectional. In special cases width was measured towards products higher coverage when lying on flat surface cross sectionally (appendix I, Figure 1)

3.3.3.4. Bulk density

Bulk density of turmeric produces on different moisture content was determined by filling a container of specific volume of box with rhizomes and measured to determine the mass of the rhizomes. It is used to design the drum volume and opening for discharge. Average mass of the rhizome was taken after three replications of filling the container of known volume and measured with the digital balance (Appendix I, Figure 2). The bulk density of turmeric was used for designing the volume of drum and discharge chute of a turmeric polisher. It is calculated by Eqn. 7, (John et al., 2019; Dilip et al., 2021).

$$Bulk\ density\ \left(\frac{kg}{m^3}\right) = \frac{weight\ of\ container\ and\ sample\ (kg) - weight\ of\ container\ (kg)}{Volume\ occupied\ (m^3)} \quad \ldots\ldots\ldots (7)$$

3.3.3.5. Sphericity

Sphericity of a material for processing machine is an important property. It is the ratio of the surface area of a sphere having the same volume as the rhizome to the surface area of the rhizome. Sphericity could be determined using the measured geometric dimensions (Eqn 8) as described by (Soyoye, et al., 2018; Dilip et al., 2021).

$$\phi = \sqrt[3]{\frac{LWT}{L}} \quad \ldots\ldots\ldots (8)$$

Where: ϕ = sphericity of turmeric rhizome;

L = length of turmeric (cm);

w = width of turmeric, (cm);

T = thickness of turmeric, (cm).

3.3.3.6. Porosity

It can be defined as the percent voids of an unconsolidated mass of materials (Mohsenin, 1986). Porosity is an important property that characterizes the amount of air spaces in a known volume of product in the drum (Poornima et al., 2019). It is a volume fraction of air in the known volume of produces and calculated by Eqn. (9) as follows,

$$P = \frac{P_t - P_b}{P_b} \times 100 \ldots\ldots\ldots (9)$$

Where: P_t is turmeric density,

P_b is bulk density

3.3.3.7 Angle of repose

The cohesion amongst the individual units of the products was defined by the angle of repose of turmeric rhizome. The product was permitted to form natural slope by placing it in a volume and allowing to flow down slowly. The pile height and diameter is measured and repose angle was calculated by eqn. (11), in accordance to (Yewle et al., 2019) with a replications.

$$\theta = \tan^{-1}\frac{2H}{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where: θ = angle of repose (in º)

H = is height (in mm)

D = is diameter (in mm)

3.3.3.8. Moisture content

Oven drying method was used to determine the moisture content of turmeric rhizome. A three samples of different moisture content turmeric was used for performance evaluation of polisher. The prepared sample of different moisture content was dried in an oven to determine the moisture content of the rhizome. Digital balance of 10 kg capacity with an accuracy of 0.01 g was used to measure the turmeric sample before and after drying in an oven for 115^{0}C. The weight loss of turmeric was recorded until a constant weight was obtained. The formula used to measure turmeric rhizome moisture content is indicated by equation (10) below (Raminder et al., 2021).

$$\text{Moisture content} = \frac{\mathrm{W_m} \times 100}{\mathrm{W_m} + \mathrm{W_d}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where: w_m is weight of moisture evaporated

W_d is weight of dry turmeric

3.3.4. Mechanical property of turmeric

3.3.4.2. Coefficient of static friction

Coefficient of static friction (μ_s) was determined on materials of different property such as galvanized sheet metal, wood and rubber Eqn. (12). It is the ratio of force necessary to begin moving the tested sample over a surface by its own weight. The angle that the inclined surface creates with the flat level when the sample starts moving was measured and calculated with help of Eqn. (12) (Dhineshkumar & Anandakumar, 2016).

$$\mu_s = \tan\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Where: θ = angle that the incline makes with the horizontal when sliding begins

μ_s = angle of static friction

3.3.4.3 Coefficient of dynamic friction

To measure dynamic coefficient of friction specified size box was placed on a test surface and filled with turmeric rhizome. Then force was applied to topless and bottomless box until it moved uniformly with a horizontal pull. The friction test was done for samples having different moisture content under investigation with eqn.(13) as indicated below.

$$\mu_d = \frac{F}{mg} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

Where: μ_d = coeff. of dynamic friction,

F = measured frictional force using pull force gauge (N),

m = sample mass in (kg) and

g = gravitational force (m/s^2).

3.3.4.4. Angle of internal friction

The value of angle of internal friction is equal to the tangent of the repose angle for the material and determined by eqn. (14). Measurement of this property is advantageous for applications in designing equipment for cracking, food milling, food processing and polishing etc (Soyoye et al., 2018). The angle of internal friction is used to estimate the lateral pressure in polisher. In design of turmeric polisher the rubbing force resulting from the impact of the expanded metal wire used for polishing the turmeric must not greater than the peak force of the turmeric. Thus, rupture force of the product should be greater than the force applied for turmeric during polishing preventing breakage of the product.

$$\psi = \tan\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

Where: ψ = angle of internal friction

θ = angle of repose/ angle of polishing drum

3.3.4.5. Hardness of the product

Hardness is an essential element for high quality polishing. Turmeric should be dry enough to resist the impact force of polishing unit for removing its outer coat. The design process has to fulfill the abrasive force that enables to remove the outer parts to produce quality polished turmeric product. The mechanical properties such as hardness, shear strength and the rheological properties affect the various operations of agricultural processing (Soyoye et al, 2018).

3.3.4.6. Rupture force

Texture analyzer (TA HD plus) was used to measure rupture force of turmeric rhizome. The speeds (pre, on test, post-test) were set optimum and recommended as 1 mm/sec, 0.75 mm/sec and 10 mm/sec, respectively. Auto trigger force was set at 100 g-force. The instrument was calibrated already on each application for different moisture content samples of the product. The rupture force was stated in a kilogram (kg) unit and measured from the resistance offered by the sample to the penetrating machine needle.

3.3.5. Conceptual model, description and principle of operation

3.3.5.1. Conceptual model for polishing machine

The conceptual model of turmeric polishing machine has three subsections, i.e. energy unit, transmission unit and processing unit. The following figure shows the conceptual model for turmeric polishing machine powered by diesel engine. The system had a diesel engine as a power source and transmits through speed reducer gearbox to the drum through shaft. The speed reducer reduces engine speed to appropriate speed for the polisher drum. The machine was designed to polish dried turmeric rhizome. In designing and developing the prototype some property of the rhizome and machine components were considered. Strength of component materials and theory of mechanisms were considered to design and construct the machine components.

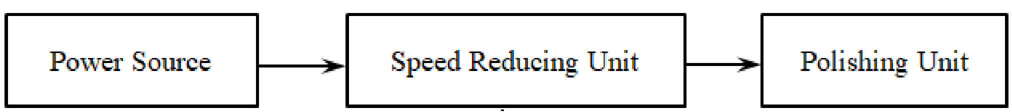
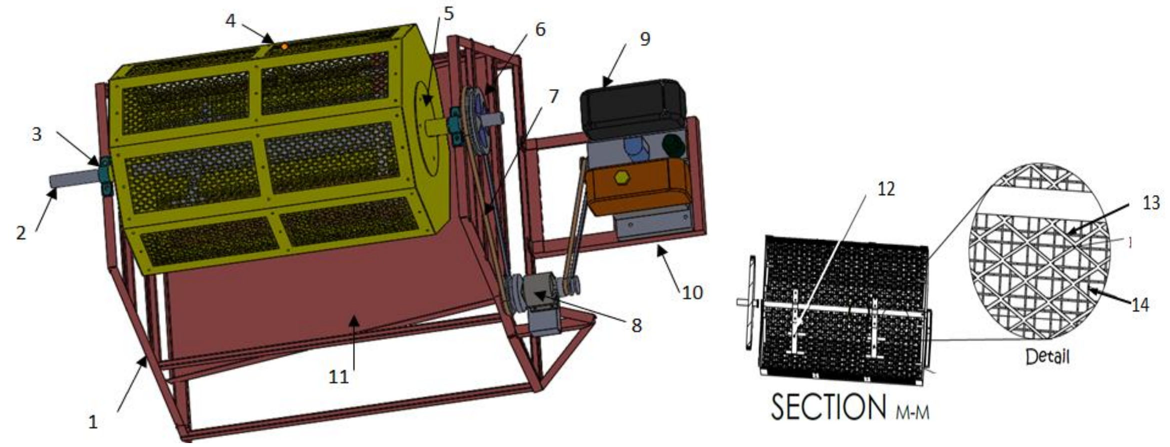


Figure 3.2. Conceptual model for turmeric polishing machine design

3.3.5.2. Turmeric polishing machine description

Developed turmeric polisher prototype has drum, different size pulleys, shaft, bearings, speed reducing unit, main frame, diesel engine, mixer, v-belt, sliding collector and cleaning unit. The parts are assembled in steps to facilitate the construction of the prototype. The materials used for designing turmeric polisher were strong and resistant enough as they undergone applied force. The drum size was 1100 mm long and 750 mm wide. The mainframe of the machine dimension is 150 mm high, 800 mm wide, and 1000 mm long and also high strength mild steel was used. The material used in designing turmeric polisher is resistant to corrosion, parts are not easily rubbed and strong enough to withstand the stubbing resistance from the turmeric.

An internal part of drum was fabricated with internal expanded metal wire and mesh wire supported by frame bars. Perforated stainless steel sheet metal is incorporated two sides of the drum for better polishing performance. In the inner part of the drum plate-shaped attachment was connected on the main shaft for uniform mixing ability and to increase the polishing efficiency of the polisher. As the machine gets rotational power from the engine attached to the frame from the bottom side, the speed reducer started to rotate receiving high rpm and outputting reduced rpm. Then the drum shaft attached to the speed reducer by through belt starts to rotate. Then polishing drum start rotating by the power received from the shaft attached to speed reducer by v-belt The polished turmeric rhizome is dropped on the slider collector and cleaner.



Key parts are: 1-Machine frame, 2- shaft, 3- Bearing, 4-Drum, 5- bushing, 6- pulley, 7- v-belt, 8-speed reducer, 9-diesel engine, 10- engine seat, 11-sliding collector 12- shaft attachment (mixer), 13-expanded metal wire, 14- wire mesh,

Figure 3.3.Turmeric polishing machine description

3.3.5.3. Principle of operation of Polishing machine

The prototype turmeric polishing machine was designed to operate on the principles of rotating drum incorporated expanded metal wire inside powered by the diesel engine as a power source through speed reducing system. It was designed to operate on the principles of rotating drum incorporated with polishing units by frictional forces powered by the diesel engine as a power source through speed reducing system. The polishing operation began from the power source with the rotating motion of the polishing unit through speed reducing gearbox and pulleys. Then, the belt and pulleys attached to the drum rotating shaft rotates the drum. Turmeric rhizomes were fed into the octagonal polishing unit through door opening used for feeding and discharging the rhizome. The rhizomes in the drum were polished by rubbing action with expanded metal wire in the drum and perforated stainless steel sheet metal at the two ends. The attachment attached on the shaft was used to disorder the product in the drum enhancing the mixing and better effacing in polishing percentage.

3.3.6. Turmeric polishing machine component design

3.3.6.1. Size, weight and volume of the drum

A. Surface Area of the drum

Area of the drum is the sum of area of eight sides composed to make octagonal drum.

Area of one side is calculated by equation (15)

$$A = s \times h \quad (15)$$

Area of 8 sides is calculated by

$$A = 8(s \times h) \quad (16)$$

B. Volume of the drum

$$V_{dr} = 2\left(1 + \sqrt{2}\right) \times s^2 \times h \quad (17)$$

Where: V_{dr} = volume of the rotating octagonal drum

s = one side length

h = the height of the drum

The polisher was designed to polish 200kg of turmeric rhizome. From the relation of mass to bulk density of the material, volume of the polisher was calculated. The determined bulk density of dry turmeric rhizome was 539.5kg/m^3. The volume of polishing drum at 75% of its holding capacity was follows. From the designing mass volume relationship (density) the volume of the drum was calculated by the following equation.

$$V = \frac{m}{\rho} \quad (18)$$

Where: V = volume

m = mass of dried turmeric

ρ = bulk density of turmeric rhizome

The volume of the container was then,

$V = w \times h \times b = 26cm \times 34cm \times 36\ cm$

$v = 32{,}266\ cm^3$

$v = 0.03227\ m^3$

Average mass of turmeric rhizome in the container after three replication is, 17.4 kg

$\rho = \frac{m}{v}$ ………………………………………………………………..……………..…..… (**)

$\rho = \frac{17.4kg}{0.03227m3}$

$\rho = 539.2\frac{kg}{m3}$

If 0.03227m^3 of volume holds a 17.4 kg of turmeric,

$V = \frac{0.03227m^3 \times 200kg}{17.4kg} = 6.454m^3kg/17.4\ kg$

$V = 0.3709m^3$

If V=0.3709 m^3 is ¾ of the required volume of the drum, the free space ¼ volume of the drum can be calculated as follows,

$V = \frac{0.25 \times 0.3709\ m^3}{0.75}$

$V = 0.1236m^3$

The total volume of the drum required is

$V = 0.3709\ m^3 + 0.1236\ m^3$

$\mathrm{V} = 0.4945\ \mathrm{m}^3$

Volume the octagonal drum is calculated by,

$\mathrm{V} = 2(1+\sqrt{2})s^2 \times h$ ………………………………………………………………… (19)

Length of the drum is adjusted to 1.1m long to calculate the width of one side by Eqn. (19),

$0.4945\text{m3} = 2(1+\sqrt{2})s^2 \times 1.1\ m$

$0.4945\text{m3} = 4.828s^2 \times 1.1\ m$

$S^2 = \frac{0.4945\ m^3}{5.31\ m} = 0.0931\ m^2$

$s = 0.305$ m

C. Weight of the rotating octagonal drum

Mass of rotating octagonal drum is the sum of all parts the drum was made up from and that of shaft. Specifically, the mass of all component parts are discussed below with a brief description.

$w = m_{dr} g$ …………………………………………………………………………… (20)

Where: w = weight of the rotating octagonal drum (N)

m_{dr} = mass of the rotating octagonal drum (kg);

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

3.3.6.2. Design of polishing unit

The rotating octagonal drum was designed based on the holding capacity, strength and drum speed to have maximum contacting surface area with the rhizome. The materials used were galvanized mesh wire and expanded metal wire reinforced by flat iron bars from the outer parts of the drum. The drum is designed to polish 200 kg of turmeric rhizome.

A. Design of drum frame

The drum frame was designed to support the other component of the frame. The selection of frame material was based on strength, rigidly for higher quality. It was aimed at higher drum strength with additional cleaning of product during polishing. The main concept of making the octagonal is to get higher drum speed during polishing operation without centrifuging.

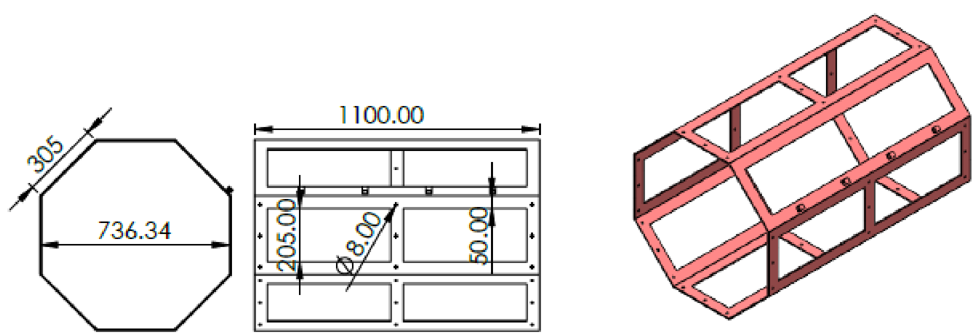


Figure 3.4. Drum frame design

B. Selection of external wire mesh

The selection of external mesh wire were based on the strength, rigidity, and opening of the mesh wire and size turmeric rhizome not to scape between the opening and was based on the minimum thickness of the turmeric rhizome. The design selection of the external mesh increases the polishing efficiency of the turmeric product. The size of external mesh wire is available by 2000mmx1000mm. The polishing drum size of one side was 1100 x 305mm which is suitable for construction of the machine drum using Eqn. (15).

$$\mathrm{A} = \mathrm{s} \times \mathrm{h} \; = \; 0.305\mathrm{m} * \; 1.1\mathrm{m}$$

$$A = \; 0.3355 \, m^2$$

Area of 8 sides is calculated by using the following Eqn. (16)

$$\mathrm{A} = 8 \, (\mathrm{s} \times \mathrm{h})$$

$$A = \; 8 \, (0.3355) m^2 = 2.684 m^2$$

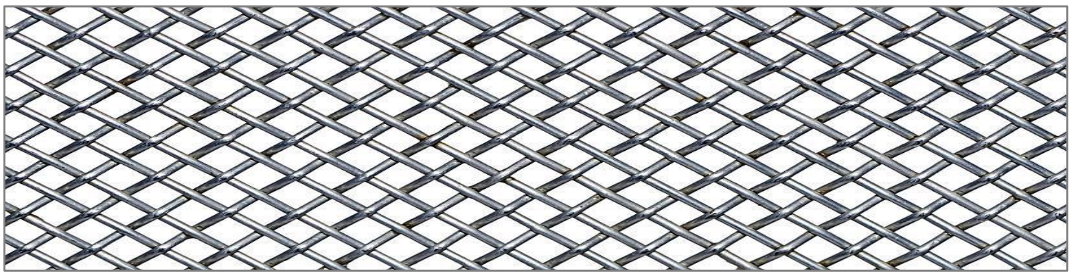


Figure 3.5. External mesh wire

C. Selection of expanded metal wire

The selection of expanded metal wire was based on the strength, rigidity, and corrosion resistance and the capacity of rubbing the product drop on the surface of the material. The size of external mesh wire is available by 2000mm x 1000mm. The polishing drum size of one side was 1100mm x 305mm which is suitable for construction of the machine drum.

$$A = sxh$$

$$\mathrm{A} = \mathrm{s} \times \mathrm{h} \; = \; 0.305\mathrm{m} \times \; 1.1\mathrm{m}$$

$$A = \; 0.3355 \, m^2$$

Area of 8 sides is calculated by using the following Eqn. (15)

$$\mathrm{A} = 8(\mathrm{s} \times \mathrm{h})$$

$$A = \; 8 \, (0.3355) m^2 = 2.684 m^2$$

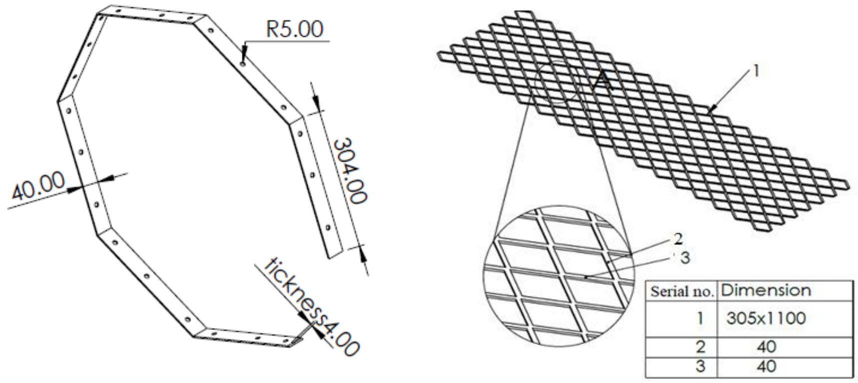


Figure 3.6. Expanded metal wire design selection

D. Design of tighter

The tighter was designed to fasten wire mesh and expanded metal wire with to drum frame with bolt. The size tighter with face width of 4omm, thickness of 4mm was made from flat iron bar. For tightening purpose, 10mm diameter bolt with nut and washer with spring was used. In other ways the bolts add polishing efficiency to the drum.

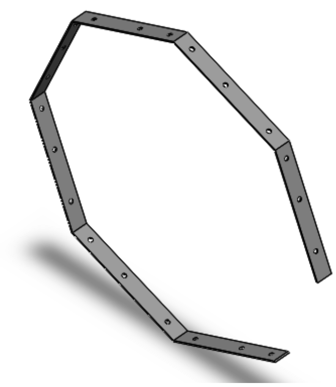


Figure 3.7. Drum frame and polishing unit tighter

E. Design of drum cover

Drum cover is used on the both ends of the drum. It slightly welded to the drum frame for strength. The perforated stainless steel with equal in size of the drum was attached to drum cover at both ends for better polishing efficiency of the drum. It enables polishing with rough perforated pegs and decreases contact with mild steel sheet metal decreasing food spoilage with corrosion and spoilage because of rubbing.

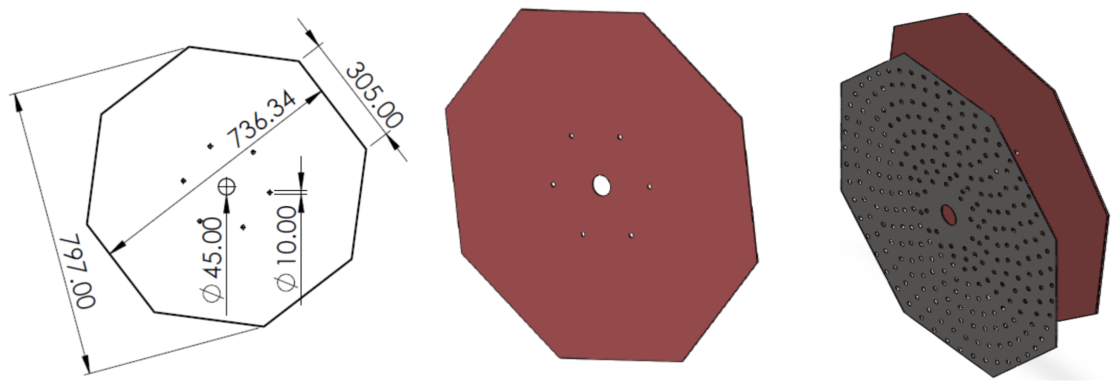


Figure 3.8. Drum cover

F. Design of the door

The door of the polisher unit should enable the free and easy feeding and discharge of turmeric into the drum for polishing. It was designed to enable polishing during drum operation. Expanded metal wire with rough surfaces is welded on the sheet metal for roughness.

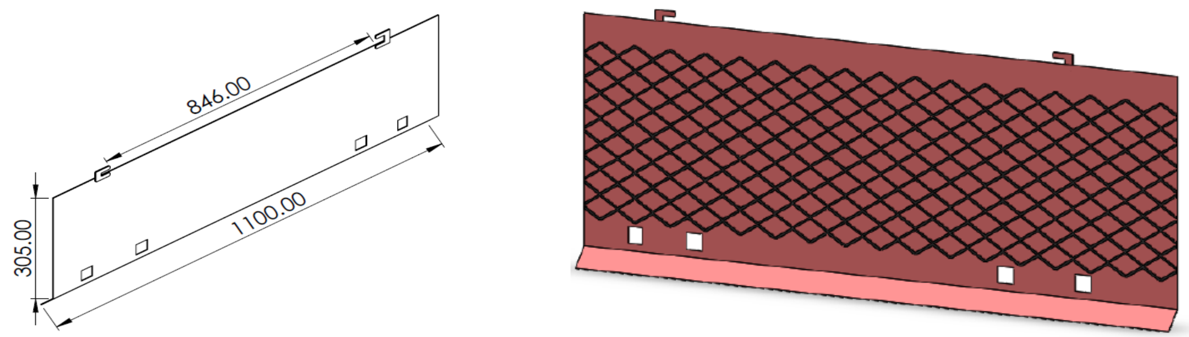


Figure 3.9. Door of designed and developed polishing machine

G. Design of bushing

Bushing was designed to hold the drum on the shaft through bolt. It was made up from mild steel sheet metal with a size of 4mm thickness and 350mm diameter and bored 60mm diameter shaft (as shown in fig. below).

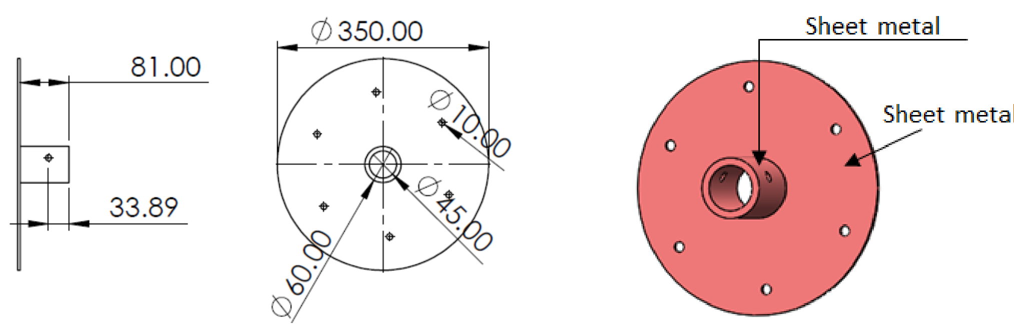


Figure 3.10. Bushing Design

3.3.6.3. Design of sliding collector

After polishing turmeric, it is required to collect the polished turmeric rhizome. Sliding collector was designed to collect the polished turmeric to one place in front of the machine in a suitable pace. Then, the product is loaded into the sack for market or home storage. The sliding collector was attached to the frame at a repose angle of 42^0.

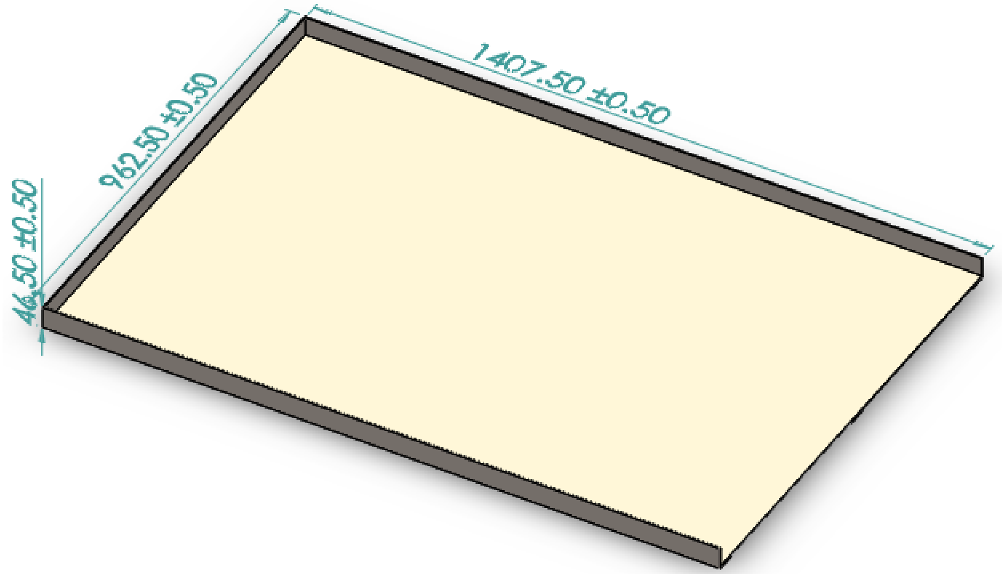


Figure 3.11. Sliding collector

3.3.6.4. Design of support frame, engine seat and machine wheel

A. Design of support frame

The octagonal drum used for polishing was supported by frame. Material strength and durability were design elements taken into account while determining the type of material used for the frame. It is designed to carry the rotating octagonal drum mechanisms, rotating pulleys, bearings, and gears. The weights carried out by the frame were drum weight, shaft weight, bearing weight, pulley and gear weights. It was constructed from 50mm x 50mm angle iron metal of thickness 5mm. As illustrated in the figure 7 below, the structure with 600 mm x 1200 mm top and bottom respectively.

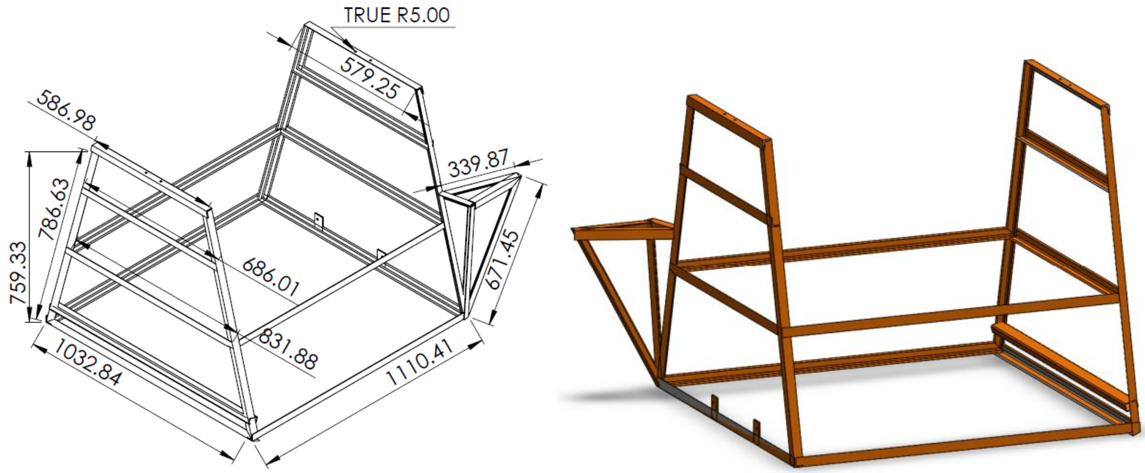


Figure 3.12. Frame of the machine

B. Design of engine seat

The polisher machine seat was designed on a simple way to remove and attach as needed. Additionally, it was made adjustable, comfortable and easy in in operation and transporting when attached to the machine. It is designed in a way that it can easily tighten and slacked on need through bolt. However the machine was designed for easiness of movement in one place to other places in transportation a well. Thus, the engine and seat can be was easily attached and detached by farmers and uneducated operator.

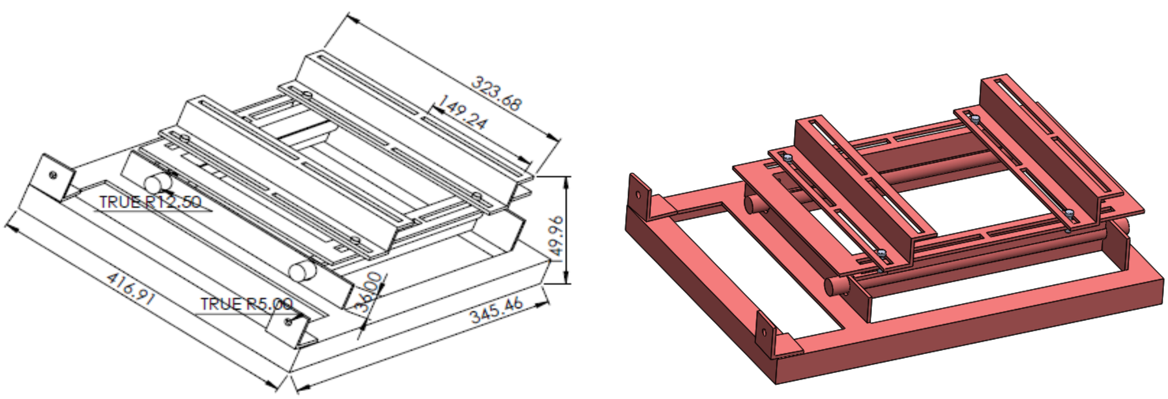


Figure 3.13. Engine seat a) sketch b) isometric view

C. Design of polisher wheel

Wheel was designed to allow easiness of machine transportation in and around working area and smooth ground. For transportation of the machine longer way from home or worksite or field it can can easily disassembled and loaded on car or tractor attached with trailer. It can be disassembled into engine, engine seat, frame, speed reducer, drum, and slider as parts. It can be easily assembled without sophistication by any person owning it without the need of technician.

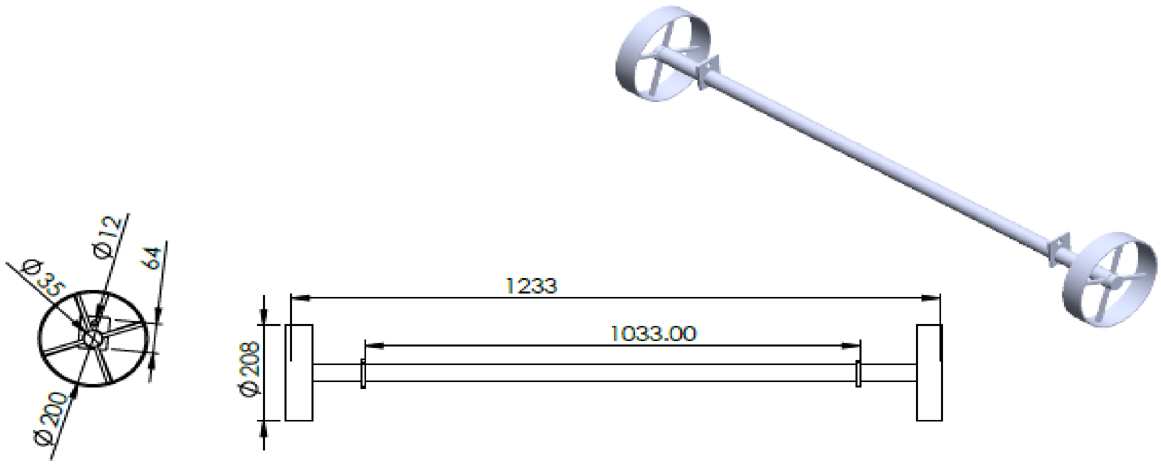


Figure 3.14. Transportation wheel for use around working area

3.3.6.5. Power transmission components design

A. Shaft design

Design of shafts of ductile materials based on strength is controlled by maximum shear stress and bending moment theory. The shaft is usually subjected to fluctuating torque and bending moments (Khurmi and Gupta, 2008) considered during the design. Thus, it was designed to transmit power under several operational and filling conditions. In order to determine the size of polisher drum shaft total forces (weight of octagonal drum, weight of maximum feed rate of turmeric rhizome, weight and reaction of pulleys) acting on the shaft were considered. Forces acting at each location on the shaft were calculated individually and the vertical and horizontal components of the forces are shown in the figure below to determine critical point on the shaft. The calculated bending moment at point where it was highest was used in calculation of shaft diameter and cold drawn steel is usually used for diameters under (76 mm) (Richard and Keith, 2011).

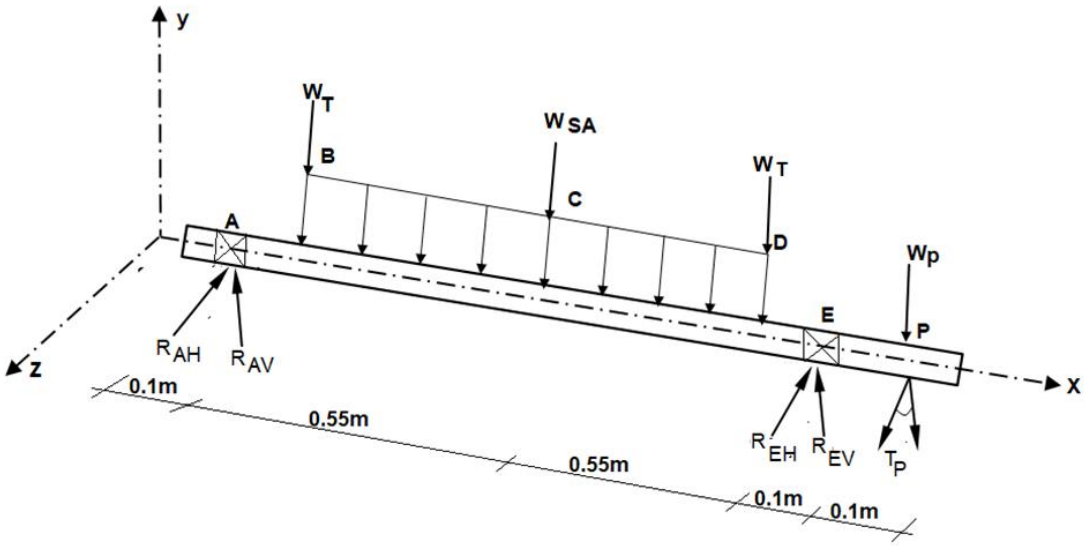


Figure 3.15. Forces applied on the polisher shaft

The resultant bending moment, were calculate by eqn. (21)

$$M_b = \sqrt{(M_V)^2 + (M_H)^2} \quad \text{............} \quad (21)$$

Where: M_b = resultant bending moments (N),

M_V = maximum bending moments on vertical plane (N) and

M_H = maximum bending moments on horizontal plane (N)

The equivalent twisting moment of the shaft is calculated by,

$$T_e = \sqrt{(K_m \times M^2 + K_t + T^2} \quad \text{............} \quad (22)$$

According to Khurmi and Gupta (2005), torque on a shaft can be calculated using Eqn. (23).

$$T = (T_1 - T_2) \times \frac{D}{2} \quad \text{............} \quad (23)$$

Where: T = torque on a shaft (N-m),

T_1 = tight side tension of belt (N),

T_2 = slack side tension of belt (N) and

D = diameter of the driven pulley (m)

For a solid shaft made from ductile material having little or no axial loading, the shaft diameter is obtained from ASME code Eqn. (24) (Khurmi & Gupta, 2008; Bako & Boman, 2017).

$$d^3 = \frac{16}{\pi Ss}\sqrt{(k_b M_b)^2 + (K_t M_t)^2} \quad \text{............} \quad (24)$$

Where: K_b = Combined shock and fatigue factor applied to bending moment,

K_t = Combined shock and fatigue factor applied to torsional moment,

Mb = Maximum bending moment, Nm,

M_t = Torsional moment, Nm,

Ss= Maximum permissible shear stress.

B. Reaction of pulley and belt on shaft

The amount of torque exerted on the speed reducer pulley by diesel engine of 5 hp and speed of 3000 rpm was determined to be 11.863 Nm by using equation 3.20 (Khurmi and Gupta, 2005).

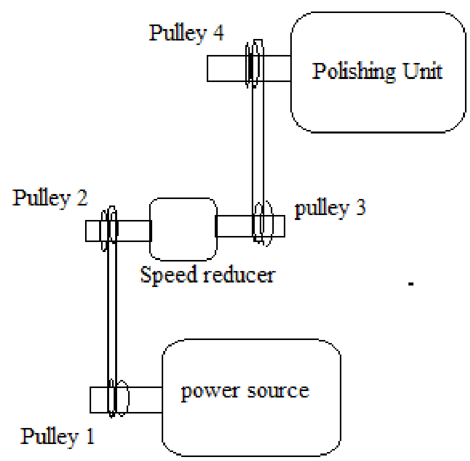
The power created due to torque and angular velocity of the Engine is

$p = T\omega$ …………………………………………………………………………...…. (25)

Where: P = Engine power (W)

ω = Engine speed (rpm) and

T = Torque (Nm)



Torque on the engine shaft,

$$T = \frac{P}{\omega}$$

$$T = \frac{5\text{hp}\,(\frac{1}{1.342\times10^{-3}})\,\frac{\text{Nm}}{\text{s.hp}}}{3000\,\frac{\text{rev}}{\text{min}}\,2\pi\,\frac{\text{rad}}{\text{rev}}\,(\frac{1}{60})\,\frac{\text{m}}{\text{s}}} = 11.863Nm$$

$T = 11.863\text{Nm}$

The torque and tension in the diesel engine (motor) side and polisher drum side were calculated because of the presence of a speed reducer in between diesel engine and drum. Therefore, the torque transfer from engine to drum shaft through has an effect on desired shaft diameter. The torque applied on the driven pulley was given by equation 3.21 (Khurmi and Gupta, 2005).

$T = (T_1 - T_2)r$ ………………………………………………………………….. (26)

Where: T = Torque exerted by Pulley

T_1 = Tight side tension of the belt in an engine side (N),

T_2 = Slack side tension of the belt in an engine side (N) and

r = Radius of pulley of speed reducer gear at the inlet (m)

According to Khurmi and Gupta (2005), the wrap angle and angle of the lap for an open belt can be calculated using equations (27) and (28) respectively.

$\sin\alpha = \frac{r1-r2}{x}$ ………………………………………………………………………………… (27)

Where: r_1 = Radius of drive pulley (mm),

r_2 = Radius of driven pulley (mm)

x = Center distance between two pulleys (mm) and

α = Warp angle ( ).

$\theta = (180 - 2\alpha)\frac{\pi}{180} rad$ ……………………………………………………………….. (28)

According to Richard and Keith (2011), the belt tension equation can be determined using eqn. (29).

$2.3\log\left(\frac{T1}{T2}\right) = \mu\theta$ ………………………………………………………………………….. (29)

Where: θ = Lap angle ( ),

T_1 = Tension in the tight side of the belt in engine side (N),

T_2 = Tension in the slack side of the belt in engine side (N) and

μ = Coefficient of static friction between belt and pulley.

From Eqn. (52) the torque exerted on the speed reducer pulley was,

$T_{sr} = (T_1 – T_2)\, r_2$

$11.863Nm = (T_1 – T_2)\, 0.0375m$

$T_1-T_2 = 316.346N$……………………………………………...……..…………..…… (a)

The minimum center distance between the diesel engine pulley and speed reducer can be calculated using Eqn. (30) (Richard, and Keith, 2011).

$x = \frac{(D_1+D_2)^2}{2} + D_1$ ………………………………………………………..…….………… (30)

$$x = \frac{(0.1 + 0.075)^2}{2} + 0.1 = 0.115m$$

$$sin\alpha = \frac{r_1 - r_2}{x} = \frac{0.05 - 0.0375}{0.115} = 0.1087$$

$$\alpha = \sin^{-1} 0.1087 = 6.24$$

$$\alpha = 6.24$$

From eqn. (28) lap angles were given by the relation

$$\theta = (180^0 - 2\alpha)\frac{\pi}{180}\ rad$$

$$\theta = (180^0 - 12.48)\frac{\pi}{180}\ rad$$

$$\theta = 167.52(0.0174)\ rad$$

$$\theta = 2.915\ rad$$

From belt tension equation (29), taking coefficient of static friction between the aluminum pulley and rubber belt was 0.3 (Richard and Keith, 2011).

$$2.3\log\left(\frac{T_1}{T_2}\right) = 0.3 \times 2.915$$

$$2.3\log\left(\frac{T_1}{T_2}\right) = 0.87$$

$\log\frac{T_1}{T_2} = 0.378$ Taking anti-log

$$\frac{T_1}{T_2} = 2.39 \quad \text{(b)}$$

From a and b that is

T1-T2 = 316.346N and T1 = 2.39T2

2.39T2 -T2 = 316.346N

1.39T2 = 316.346N

T2 = 227.587

$T_1 = 2.39T_2$ from the relation, then we get

$T_1 = 543.93$N

With a constant power, a gear ratio to decrease the angular velocity will simultaneously increase torque (Richard and Keith, 2011). According to them the gear ratio, or train value, for the gear train is calculated by,

$$\mathrm{T}_2\omega_2 = \mathrm{T}_3\omega_3 \quad (32)$$

$$\mathrm{T}_3 = \frac{\mathrm{T}_2\omega_2}{\omega_3}$$

$$\mathrm{T}_3 = \frac{8.911 \times 418}{8.373}$$

$$\mathrm{T}_3 = 443.368\mathrm{Nm}$$

To calculate the torque transmitted to drum we can use the relation between speed and torque as Eqn. (33) (Khurmi and Gupta, 2005).

$$\frac{\mathrm{N}_3}{\mathrm{N}_4} = \frac{\mathrm{T}_4}{\mathrm{T}_3} \quad (33)$$

Where: T_3 = torque on speed reducer shaft (Nm),

T_4 = torque on drum shaft (Nm),

N_3 = outlet speed reducer speed (rpm) and

N_4 = drum speed (rpm)

Thus from the above equation, drum shaft torque is calculated by,

$$T_4 = \frac{N_3}{N_4} T_{sr}$$

$$T4 = \frac{80rpm \times 443.368}{70rpm}$$

$$T = 506.7 \text{ Nm}$$

Belt tension created due to the torque transferred to the drum is calculated by the following equation

$$T_{dr} = (T_3 - T_4)\, r_4$$

$$506.7\text{Nm} = (T3 - T4)\, 0.1515m$$

$$T_3 - T_4 = 3339.9N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{ a`}$$

From equations (28), (29), and (30) warp angle, lap angel and center distance for drum side belt and pulley can be calculated as shown below.

$$sin\alpha = \frac{r_3 - r_4}{x}$$

$$x = \frac{(D_3 + D_4)}{2} + D_3$$

$$x = \frac{(0.14 + 0.16)}{2} + 0.14m$$

$$\text{x} = 0.29\text{m}$$

$$sin\alpha = \frac{0.07 - 0.1515}{0.29} = -0.281$$

$$\alpha = 16^0$$

$$\theta = (180^0 - 2\alpha)\ \frac{\pi}{180^0} rad$$

$$\theta = (180^0 - 2x16)\ \frac{3.142}{180^0} rad$$

$$\theta = (180^0 - 32)\ 0.017rad\ \ldots$$

$$\theta = 2.516rad$$

From belt tension equation of (29)

$$2.3 \log\left(\frac{T3}{T4}\right) = u\theta$$

$$\log\left(\frac{T3}{T4}\right) = \frac{0.3\times 2.516}{2.3}$$

$$\log\left(\frac{T3}{T4}\right) = 0.357$$

$\frac{T3}{T4} = 2.13$ ………………………………………………………………………………..b`

From a` and b` we get

$T_3 - T_4 = 3339.9\text{N}$ and $T_3 = 2.13\,T_4$

$2.13\,T4 - T4 = 3339.9N$

$T_4 = 2955.66\text{N}$

$T_3 = 5{,}993.68\text{N}$

Resultant Force because of tension of pulley is calculated and is 8949.34N and resolved into vertical and horizontal axis

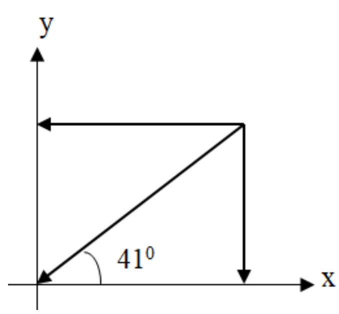


Figure 3.16. Resultant force due to belt on the drum pulley

Therefore, the load on the shaft due to the pulley and belt was the sum of tension on tight and slack side of the belt and pulley weight which is 8990.38N. The horizontal and vertical components of the tension force are 6785.12N, 5898.22N respectively.

C. Forces acting on the shaft due to drum and product weight

Weight of octagonal drum is the sum of the weight of flat iron, external mesh wire, weight expanded metal wire, perforated stainless steel, bolts and nuts, bushing, drum cover, door and shaft attachment. The weight of the drum is calculated as 967.257N. Detailed description of the mass is presented in (Appendix B, table 2).

Weight of Turmeric,

$$W_{turmeric} = \ mass\ (m) in\ Kg \times 9.81 kgm/s2$$

$$= 200kg \times 9.81 m/s^2$$

$$= 1962N$$

Forces acting on the shaft are weight of the drum and half weight of turmeric rhizome. The forces of the drum and turmeric acting on the shaft at two points in contact with the shaft through bushing at point B and D. Therefore the forces acting on the shaft due to drum weight and the rhizomes at point B and D were,

At point B the forces acting on the shaft are,

$$W_{shaft\ B} = \frac{1}{2} W_{drum} + \frac{1}{4} W_{Rhizome} \qquad (34)$$

$$W_{shaft\ B} = \frac{1}{2}(967.257\text{N}) + \frac{1}{2}(1962N)$$

$$W_{shaft\ B} = 483.628N + 490.5N$$

$$974.128N$$

At point D the forces acting on the shaft are,

$$W_{shaft\ D} = \frac{1}{2} W_{drum} + \frac{1}{4} W_{Rhizome}$$

$$W_{shaft\ D} = \frac{1}{2}(967.257\text{N}) + \frac{1}{4}(1962N)$$

$$W_{shaft\ D} = 483.628N + 490.5N$$

$$= 974.128\text{N}$$

As described above the half drum volume of turmeric weight of the distributed load of the rhizome acts on the shaft and the weight was calculated by,

$$W_{shaft\ C} = \frac{1}{2} W_{Rhizome}$$

$$W_{shaft\ C} = \frac{1}{2}(1962)$$

$$W_{shaft\ C} = 981N$$

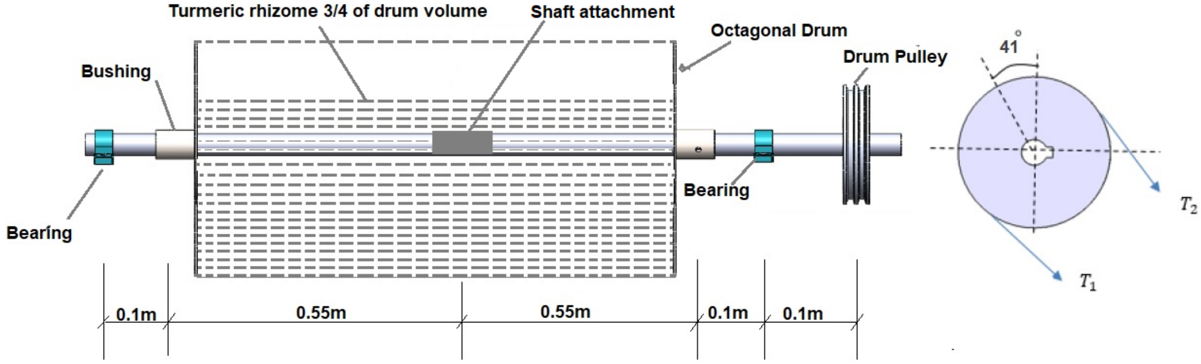


Figure 3.17. Layout of shaft components

Half weight of the turmeric rhizome in the drum applies force on the shaft while the other half is applied on the drum itself. Forces acting at each location on the shaft were computed separately and the vertical and horizontal components of the forces are shown in the figure below.

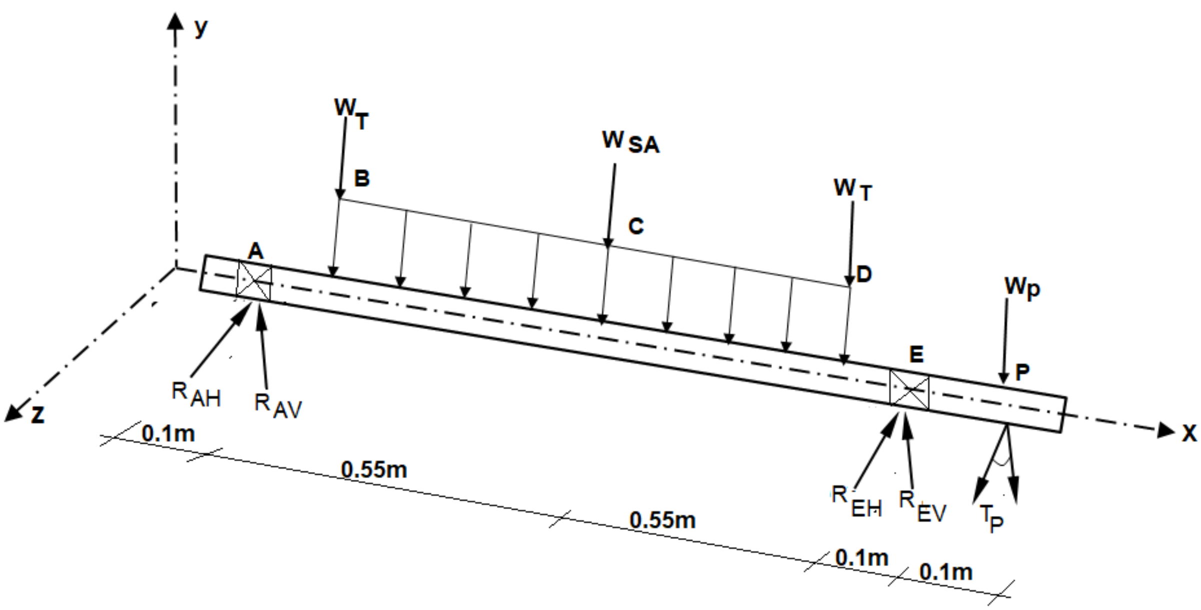


Figure 3.18. Free body diagram of all forces acting on the shaft

Where: R_{AH} = Horizontal bearing reaction at A (N)

R_{AV} = Vertical bearing reaction at A (N)

R_{EH} = Horizontal bearing reaction at E (N)

R_{EV} = Vertical bearing reaction at E (N)

W_P = Weight of pulley at P (N)

W_T = Weight of turmeric and drum at bushing B and D (N)

T_P = Total belt tension at P (N)

W_{SA}= Weight of Shaft attachment at C (N)

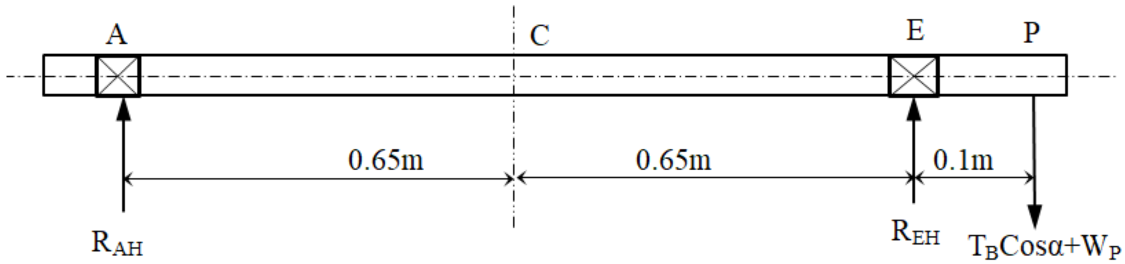


Figure 3.19. Horizontal components of forces acting on the drum shaft

Analysis of horizontal forces acting on the shaft

$$\mathrm{T_B Cos\alpha} + \mathrm{W_P} = 6{,}807.68N$$

$\sum \mathrm{Fx} = 0$, to find the reaction forces at point A and E

$$\mathrm{R_{AH}} + \mathrm{R_{EH}} - \mathrm{T_B Cos\alpha} + \mathrm{W_P} = 0$$

$$\mathrm{R_{AH}}+\mathrm{R_{EH}} = 6{,}807.68N$$

$\sum \mathrm{M}_E = 0$, taking anticlockwise as positive,

$$-1.3R_{AH} + 6{,}807.68N(0.1m) = 0$$

$$(-1.3\mathrm{R_{AH}}) + 6{,}80.768N = 0$$

Then the forces acting at point A and at Point E is equal to,

$$\mathrm{R_{AH}} = -523.667\mathrm{N}$$

$$\mathrm{R_{EH}} = 7331.33\mathrm{N}$$

The horizontal shear force and bending moment diagram is shown below

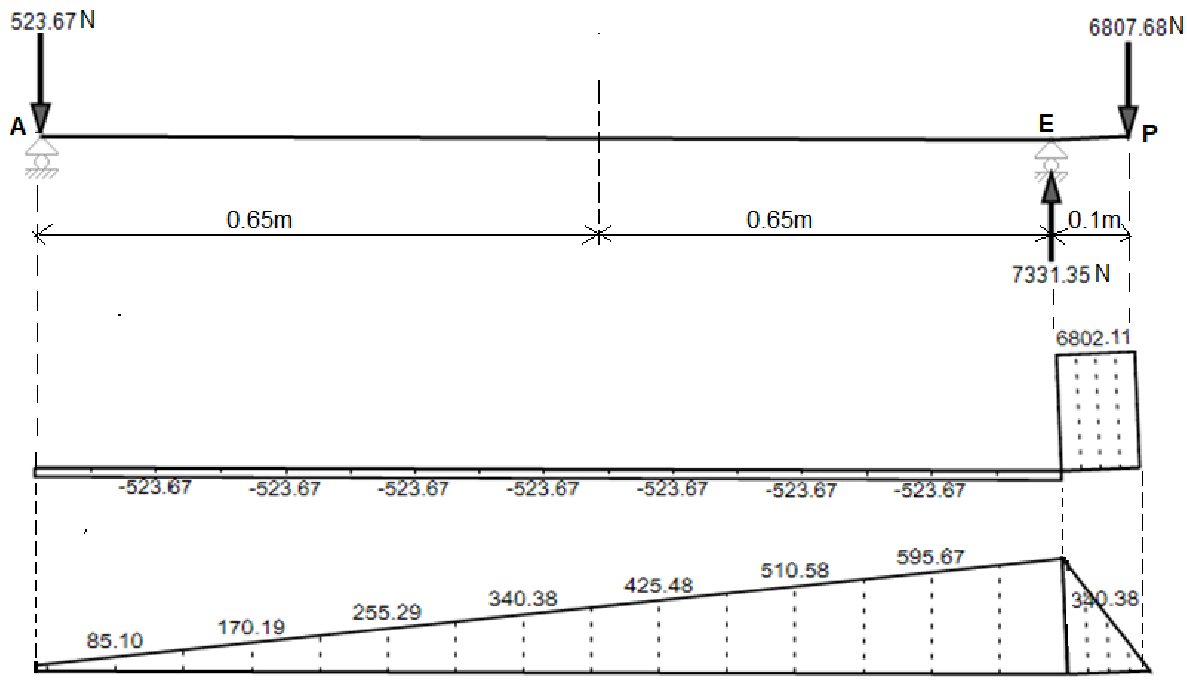


Figure 3.20. Free shear force and bending moment free boy diagram on horizontal plane

Analysis of horizontal component force on the drum shaft is shown on the figure below. We know that the moments at pint A (R_{AH}) and point P (R_{PH}) is equal to zero. Then, the bending moment at point P is

$$M_{AH} = 0$$

$$M_{EH} = 6807.68N \times 0.1m = 680.77Nm$$

$$M_{PH} = 0$$

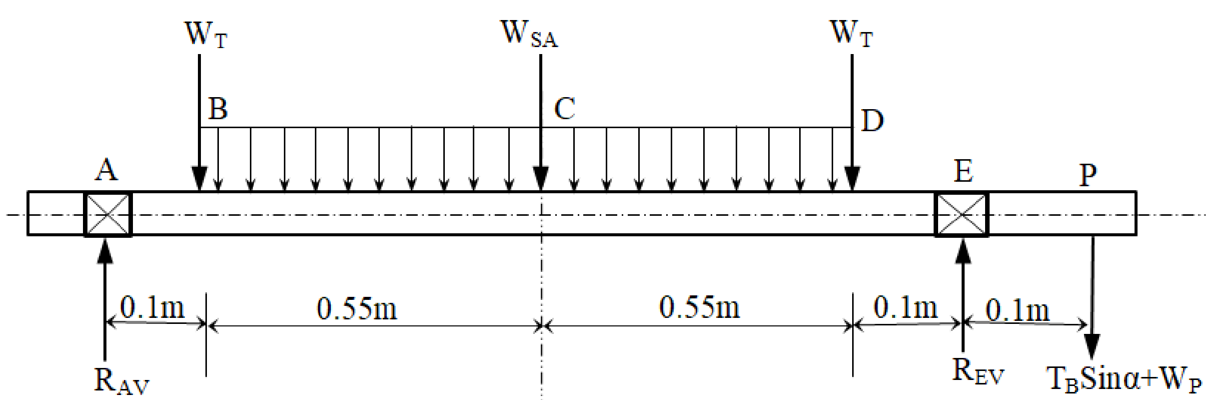


Figure 3.21. Vertical components of forces acting on the drum shaft

$\sum F_y = 0$, taking downward forces as negative, find vertical reaction forces at point A and E

$\therefore T_B sin\alpha + W_p =$ 5920.783N, W_T = 974.13N, W_{SA} = 48.75N

$R_{AV} - W_T - (W_{SA} + DL) - W_T + R_{EV} + (T_B \sin\alpha + W_p) = 0$

$R_{AV} - 974.13N - 1029.75N - 974.13N + R_{EV} + 5920.783N = 0$

$R_{AV} + R_{EV} = 2942.77N$

$R_{AV} = 2942.77N - R_{EV}$ ………………………………………………..………..*

$\sum M_E = 0$, taking anticlockwise as positive,

$-1.3R_{AV} - 1.2\,m(974.13N) - 0.55m(48.75N) - 0.65(974.13N) + 0.1R_{EV} +$
$0.1m\,(5898.22N) = 0$

$(-1.3R_{AV}) + 0.1R_{EV} - 1239.13 = 0$

$(-1.3R_{AV}) + 0.1R_{EV} = 1239.13$ ……………………………………………… **

By substituting * into ** the vertical components forces at point A and point E is equal to

$R_{AV} = 1035.99N$

$R_{EV} = 7867.67N$

The vertical shear force and bending moment diagram is shown below. The maximum bending moment and shear forces are located at E.

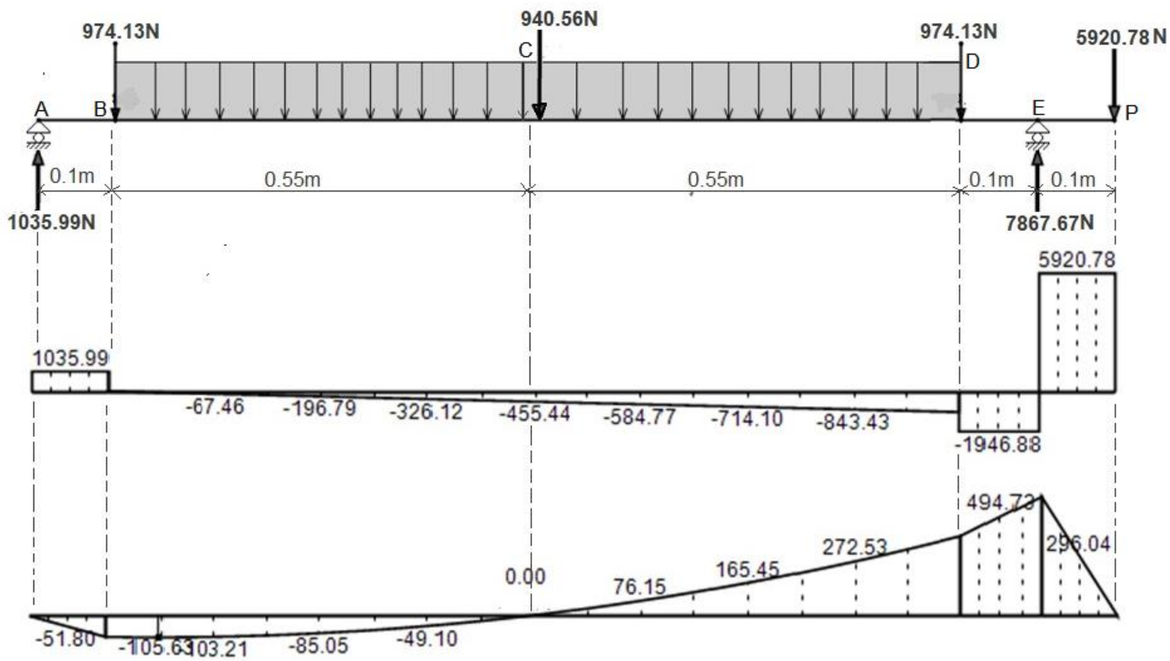


Figure 3.22. Free shear force and bending moment free body diagram on vertical plane

Analysis of vertical force on the drum shaft is shown on the figure below. We know that the moments at pint A (R_{AV}) and point P (R_{PV}) is equal to zero. Then the bending moment at point P is

$$M_A = A\,(R_{AV}) = P\,(R_{PV}) = 0$$

$$M_{BV} = 0.1\text{m}\,(-1035.99\text{N}) = -\,103.6\text{Nm}$$

$$M_{CV} = 1035.99\text{N}(0.65) - 974.13(0.55) - 940(0.55)(0.275) = -4.553\text{Nm}$$

$$M_{DV} = 1035.99\text{N}(1.2) - 974.13(1.1) - 940(0.55)(0.275) = 313.82\text{Nm}$$

$$M_{EV} = 592\text{N} \times 0.1\text{m} = 592\text{Nm}$$

$$M_P = 0$$

The resultant bending moment was calculated by the equation Maximum vertical Bending moment is at point E (M_V = 592Nm), and horizontal components side is at point E (M_H 680.77Nm) and then the resultant bending moment is calculated by,

$$M_R = \sqrt{(M_V)^2 + (M_H)^2} \quad \ldots\ldots (35)$$

Where: M_R = resultant bending moments (N),

M_V = maximum bending moments on a vertical plane (N) and

M_H = maximum bending moments on a horizontal plane (N).

The diameter of the shaft is calculated by

$$d = \frac{16}{\pi sa}\sqrt{(C_b K_b M_r)^2 + (C_t K_t T)^2} \quad \ldots\ldots (36)$$

Where: d = diameter of the shaft (mm),

K_b = combine shock and fatigue factor applied to bending moment,

M_r = Resultant bending moment (N-m),

K_t = combine shock and fatigue factor applied to torsional moment,

T = torque (Nm),

C_b = stress concentration factor for bending,

C_t = stress concentration factor for a torsional moment and

S_a = shear strength (N/m2).

The value of C_t, K_b was taken as 1.2 and 1.2 as recommended by Richard and Kelth (2011), the torque of the shaft was estimated by using Eqn (33) found 227Nm). By using bending moment and shear force values and equations the diameter of the shaft was determined to be 44.85 rounded to 45 by using the Eqn. (36).

3.3.6.6. Design of shaft attachment

Shaft attachment was designed to enhance the mixing and uniformity of turmeric in the octagonal drum. It is made from corrosion resistant stainless steel sheet metal having 3mm thickness, 30mm width to prevent rust and poisoning of product. The angle like structure having 3mm thickness were bent by CNC machine and attached by welding. It enables and helps to mix the turmeric rhizome in the drum.

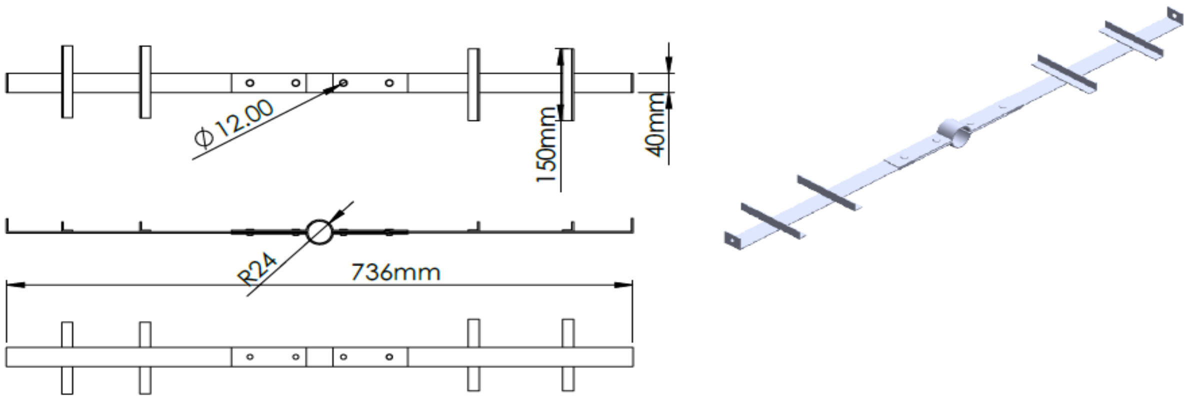


Figure 3. 23. Shaft attachment (stainless steel)

3.3.6.7 Selection of bearing for drum shaft

A bearing helps to permit a relative motion between the contact surfaces of members while carrying a load (Suleiman, A.I, 2020). The bearing was selected depending on the radial loads resulting from the belt tension, dynamic load rating, bearing carrying capacity and diameter of bore.

The resultant reaction loads resulted from pulley and rotating shaft is calculated by Eqn. (37)

$$R = \left(\sqrt{{R_{BX}}^2 + {R_{BY}}^2}\right) \ldots\ldots (37)$$

Where: R_{BX} = maximum resultant force acting on a bearing on horizontal plane (KN),

R_{BY} = maximum resultant force acting on a bearing on vertical plane (KN),

R = maximum resultant reaction force on the bearing (KN),

$$R = \sqrt{(6785.12N)^2 + (5898.22N)^2}$$

$$R = 8990.375N$$

The bearing design load was calculated using Robert (2004), formula

$$Pd = VR \ldots\ldots (38)$$

Where: P_d = load of the bearing (N).

V= rotation factor 1.0 because of inner surface rotation

R = load due to drum and the product (N)

$$Pd = 1.0 \times 8990.375N$$

$$Pd = 8990.375$$

By considering 42hr in a week and for three years of life design life of bearing can be calculated from equation (39)

$$\text{Ld} = \text{Rotational speed x Operation hour} \ldots \qquad (39)$$

$$\text{Ld} = 85\text{rpm x } 6048\text{hr}$$

$$\text{Ld} = 514080$$

The bearing were selected for dynamic load capacity (C), K=3 for ball bearings, design load of bearing (Ld) and diameter and finally width by the equation (40).

$$\text{C} = Pd\left(\frac{Ld}{10^6}\right)^{\frac{1}{k}} \ldots \qquad (40)$$

Where: C= dynamic load rating (N)

L_d = Design life of bearing

K= 3 for ball bearing

$$\text{C} = 8990.375\text{N}\left(\frac{514080}{10^6}\right)^{\frac{1}{3}}$$

$$\text{C} = 7202.026\text{N}$$

The resultant reaction force on the bearing is calculated by eqn (62) and found to be 8.99KN from the reaction forces at the bearing position. And dynamic load rating can be determined using Eqn. (61), (Khurmi and Gupta, 2005; Richard and Keith, 2011) was 7.202KN.

The size of a bearing to be used depends on the designed size of shaft required and by the available space. Thus, the dynamic loading the designed bearing was 7.202KN which was less the selected bearing (P209) because of shaft diameter (45mm)

3.3.6.8. Design of pulley

As stated in Khurmi & Gupta (2005), the pulleys are used to transmit power from one shaft to another using ropes, V-belts or flat belts. The pulleys must be in perfect alignment to allow the belt to travel in a line normal to the pulley faces. Since the velocity ratio is the inverse ratio of the diameters of driving and driven pulleys, therefore the pulley diameters should be carefully selected to have the desired velocity ratio. Pulleys are the greatest parts among power transmission components in machine and mechanical systems.

The speed of the octagonal polishing machine drum was related by using Eqn. (41) in accordance with (Richard & Keith, 2011).

$$\frac{N1}{N2} = \frac{D2}{D1} \quad \ldots\ldots \quad (41)$$

Where: N1 = maximum angular speed of driven pulley (rpm),

N2 = maximum angular speed of driving pulley (rpm).

The peripheral velocity (V_p) of the driving pulley and the diameter of driven pulley D_2, was obtained from Equations (42) and (43) given respectively by (Moghe et al., 2012).

$$V_p = \frac{\pi \times D \times N}{60x1000} \quad \ldots\ldots \quad (42)$$

$$\pi x D_1 \times N_1 = \pi \times D_2 \times N_2 \quad \ldots\ldots \quad (43)$$

Where: D_1= is diameter of pulley 1

D_2= is diameter of pulley 2

N_1= revolution of pulley 1

N_2= is revolution of pulley 2

From equation (43) above, after omitting common letter from both sides, then we can get,

$$D_1 N_1 = D_2 N_2 \quad \ldots\ldots \quad (44)$$

We have N_1 the speed of the engine, and fixed the diameter (D_1 for pulley 1, attached on engine shaft. Now we can calculate for N_2,

$$N_2 = \frac{D_1 N_1}{D_2}$$

$$N_2 = \frac{100mm \times 3000\ rpm}{75mm}$$

$$N_2 = \frac{300000mm\ .rpm}{75mm} = 4000rpm$$

The design of pulley was based on the speed required for optimum polishing, the ratio of speed reducing gearbox and durability required and strength was considered. The diameter of driven pulley was designed to be 140mm using Eqn. (66). Figure 3.25 shows designed for the developed machine. Width of the pulley or face of the pulley was computed was found to be 16.25 mm using equation (67) stated below. The thicknesses of driven pulley depth and thickness was for single belt were calculated as 11mm and 7mm respectively using eqn. (45).

$$B = b + 0.25b = 1.25b \quad \ldots\ldots \quad (45)$$

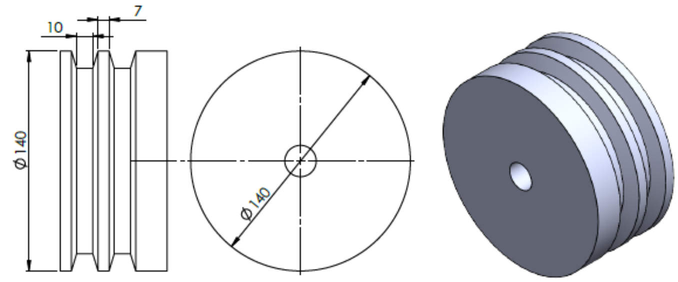


Figure 3.24. Drum shaft pulley

3.3.6.9. Belt selection

Belt selection is based on the factors such as speed of machine shaft driving and driven pulley speed ratio, power to be transmitted, center distance between the shafts and service conditions. They may be classified as flat, v-belt and circular belt based on their geometry.

The selection of belt was made by using the nominal pitch length (1566mm) and center distance (1589mm) determined from Eqn. (48). The selected standard pitch length is 1566mm for engine and speed reducer pulley. So based on minimum pulley diameters (75mm) recommended for two standard V-belt size of B-60 sufficient to transmit power from engine to speed reducer was selected. The belt cross-sectional area was calculated using equation (47). From the selected belt of 17mm top width, thickness of 11mm, thickness, bottom width of 10.5mm, the surface area was calculated to be 152. The groove angle of the pulley was taken as 40˚ which is mean of the range. The same procedure was used to select belt length of 2388mm, depth 11mm, width 17mm, pitch Length 2429mm and weight of 470g V- belt.

$$m = \rho \times A \quad (46)$$

$$A = \frac{(b-x)}{2}t + xt \quad (47)$$

Where: m = mass per unit length (kg/m)

A= belt cross section area (m2)

ρ = density of belt rubber (kg.m.-3)

b =top width (mm)

x =bottom width (mm)

t = thickness (mm)

The belts used between diesel engine, speed reducer and drum pulley were selected according to (Richard and Keith, 2011) with calculation. Therefore, nominal pitch length is calculated by using eqn (48)

$$L = 2C + \frac{\pi}{2}(D_1 + D_2) + \frac{D_2 - D_1}{2C} \quad \text{………………………………………………………...…. (48)}$$

Where: D_1 and D_2 = driving and driven pulleys diameters (m),

C = center distance between two adjacent pulleys (m),

L = belt length (m),

n_1= speed of smaller pulley in RPM

n_2 = speed larger pulley in RPM

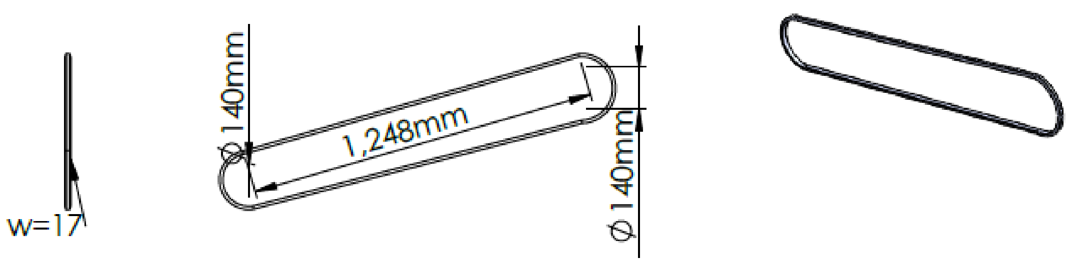


Figure 3.25. V-belt design and selection

3.3.7. Power estimation to operate the polisher

Different types of drums with a same principle of operation were used in various economic activities of people (Teruchcov et al., 2019). The most commonly used devices are agricultural product processing drums. Drum devices are used to implement many of the processes that are based on mixing, rubbing or decorticating through rotation principle. The value of the torque developed by a rotational body is given by the product of the Force F_c causing the motion multiplied by the radius of rotation (r) and given by Eqn. (49).

$$T = F_c \times r \quad \text{……………………………………………………………………….…….. (49)}$$

Where: Fc = is the centrifugal force required to produce acceleration (N)

r = radius of rotation (radius of the rotating octagonal drum)

$$Fc = ma = m\omega^2 r \quad \text{…………………………………………………………………………. (50)}$$

Where: m = mass of the rotating octagonal drum (kg)

ω = angular velocity (rad/s) = 2πN/60

N = rotational speed of octagonal drum (rpm)

The required power to rotate turmeric rhizome inside octagonal drum chamber can be determined from the nature of the rhizome "movement on the surface of octagonal drum and depends on the coefficient of frictions between turmeric rhizome and expanded metal wire, repose angle, centripetal acceleration $r\omega^2$ (operating condition kinematics). Depending upon this relationship, the rhizomes in the drum may slide along drum surfaces performing rubbing, separate and flight or may move with the surface being at rest relative to it (Bosoi et al., 1991). In last case, the rhizomes would not polished Neglecting the centrifugation of turmeric rhizome in the octagonal drum, the release of turmeric rhizome polisher through drum depends upon the relative velocity and the forces acting on each rhizome.

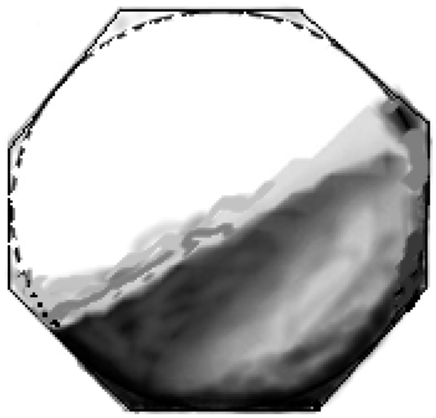


Figure 3.26. Model of movement of the product in the drum (left side view)

Turmeric rhizomes in the drum face two main forces i.e. normal force, pressing turmeric rhizome and drum surface together and frictional force resisting motion of these two surfaces. The motion of the rhizome on the internal octagonal drum surface is not determined by the tangential forces alone. But, if the resultant of the normal forces (F_n) is not directed towards the octagonal drum surface, the rhizome will lose contact with the drum and there is no polishing. Teruchcov et a., (2019) developed force analysis equation based on Figure 4 below. According to Parag et al., (2020), the contact forces of particles in rotating drum is composed of tangential contact forces and normal contact forces.

$$Fc = f_n + f_t \quad \ldots\ldots (51)$$

Where: F_C = Centrifugal Fore

F_n = normal force

F_t = frictional force

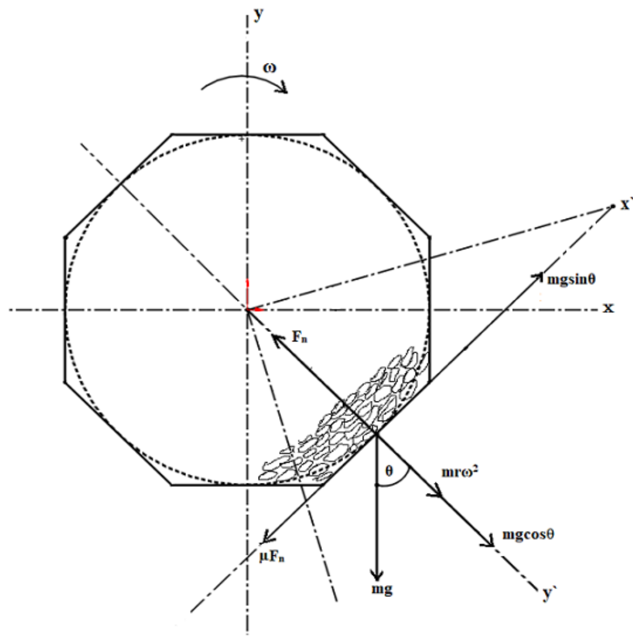


Figure 3.27. The forces acting on a particle of turmeric rhizome in drum

The behavior of a turmeric rhizome in the drum depends on the octagonal drum angular speed at a given radius with other factors such as turmeric layers, internal friction, etc. that affect the performance of a polishing machine (Guz,1999). The motion of the turmeric rhizome through the octagonal drum in the normal and tangential direction was determined using Eqn. (52) to (53) (Yang et. al., 2003, Teruchcov et al., 2019)

$F_n = mr\omega^2 + mgcos\theta$ ………………………………….………………...…………. (52)

$Ft = mgsin\theta = \mu F_n$ ……………………………………………….………………… (53)

Where: F_n = reaction force (N),

θ = angular position of the turmeric particle on the drum surface (let ά=15°),

μ = coefficient of friction between the turmeric and the octagonal drum surface

m = mass of the turmeric rhizome (Kg),

r = radius of the drum (m) and

ω = angular revolution, (rad/s).

The angular revolution of turmeric rhizome inside rotating drum was determined from Eqns. (54) (Teruchcov *et. al.*, 2019)

$\omega^2 = \frac{g}{\mu r}(sin\theta - \mu cos\theta)$ ……….………………...…………………………...……….. (54)

At θ = 45^0, the number of the angular revolutions of the drum was calculated by,

$$\omega^2 = \frac{9.81}{0.25x0.368}(sin45 - 0.252cos45)$$

$\omega^2 = 55.854$

$\omega = 7.473$

The normal contact force of turmeric in the drum is calculated as follows

$F_n = mr\omega^2 + mgcos\theta$

$F_n = 200kg \times\ 0.368\ \times\ (7.473rad/s)^2 + 200kg \times\ 9.81\frac{m}{s^2}\ \times\ cos45$

$\mathrm{F_n} = 5497.988\mathrm{N}$

The tangential contact force of turmeric in the drum is calculated as follows

$Ft = \mu F_n$

$\mathrm{Ft} = 0.252 \times 5497.988\ = 1385.49$

$\mathrm{Ft} = 1385.49$

The normal force, the torque, angular velocity and power required to polish turmeric rhizome can be found using Eqns. (52), (53), (55) and (57) (Khurmi and Gupta, 2005).

$T = F_n \times r$ …………………………………………………………………………….. (55)

$\omega = \frac{2\pi n}{60}$ ……………………………………………………………………….. (56)

$P = T \times \omega$ ……………………………………………………………………….. (57)

Where: P = power required (watts),

T = torque required to drive octagonal drum (Nm),

ω = angular velocity (rad/s),

n = speed of the octagonal drum in rpm and

r = radius of octagonal drum (m).

$\mathrm{F_n}$ = normal fore

Under the action of these forces, the material elementary sector is pressed against the inner wall of the container; creating the reaction force of the normal pressure *N*, as well as the friction force F_{tr} of the material against the container wall. Overcoming these forces, there is a force applied to the friction of the rotating octagonal wall of container F_{tr} onto the particle *M* (Teruchcov, 2019).

$\frac{\sum F_x = Fc - N + G*cos(\alpha) = 0}{\sum F_y = Ftr - G*sin(\alpha) = 0}$ ……………………………………………………………… (58)

$\frac{\sum N = Fc + G\times cos(\alpha)}{Ftr = G\times sin(\alpha)}$ ……………………………………………………………….. (59)

Where: F_c = centrifugal Force

N =Normal fore

G = gravitational force

F_{tr} = frictional force

Within the presence of the drum rotation, a moment of turmeric friction against the surface is created. If the friction force F_f is small with a small friction coefficient *f* of the turmeric against the inner drum surfaces, or a large angle of the wall placement relative to the horizontal (Teruchcov, 2019). Then there is a possibility for turmeric to slide along the inner drum surfaces. This condition is described by eqn.58 above, where $F_f = N$ x f otherwise, turmeric rhizome is lifted to a certain height, corresponding to the location of the turmeric at a certain angle from the lowest point of the container (Teruchcov, 2019). Then, the surfaces of turmeric on the outer layer are rubbed due to less centrifugal force.

The product in drum makes at repose angle equal to octagonal drum sides. This condition is described by eqn (59) in the system. The power required to rotate polishing drum with turmeric rhizome in the drum was calculated by equation (60). The radius of octagonal drum is taken as the average radius of inscribing and circumscribing cycles of the octagonal drum.

$P_d = m_{dr} \times r_{dr} \times g \times \omega$ ………………………………………………..…...……….. (60)

Power required to rotate drum shaft was determined from Eqn. (61) below.

$P_s = m_{shaft} \times r_{shaft} \times g \times \omega$ …………...…………………………………...……….. (61)

Where: P = required power to rotate octagonal drum (w)

m_{dr} = mass of octagonal drum with turmeric (kg)

r_{dr} = radius of octagonal drum (m)

m_{shaft} = mass of shaft in (kg)

r_{shaft} = radius of Shaft in (m)

g = gravitational acceleration in (m/s^2)

ω = angular revolutions (rad/s^2)

Mass of shaft is calculated from the relation of mass density,

$m = \rho V$

$V = \pi r^2 h$

$V = 3.14 \times (0.020)^2 \times 1.56m = 0.0019m^3$

$$m = 7860\frac{kg}{m^3} \times\ 0.00196m^3 = 14.934kg$$

The power required to rotate the shaft is then,

$$P = 14.934kg\ \times\ 9.81\frac{m}{s2} \times 0.020m\ \times\ 1.936\frac{rad}{s}$$

$$P = 5.673watts = 0.005673KW$$

The power required to rotate the drum with turmeric is calculated as follows,

$$m_T = 98.6kg + 200kg$$

$$m_T = 298.6kg$$

$$P = 298.6kg \times 9.81m/s^2 \times 0.3932m \times 1.936rad/s$$

$$\mathrm{P} = 2229.86\mathrm{w}$$

Total power required to rotate the drum with ¾ full is,

$$\mathrm{P_T} = 2229.86\mathrm{w} + 5.673\mathrm{w}$$

$$\mathrm{P} = 2235.53\mathrm{W}$$

$$\mathrm{P} = 2235.53\mathrm{w} \times 1.5$$

$$\mathrm{P} = 3353.3\mathrm{W} = 3.353\mathrm{KW}$$

The minimum power required to rotate the system multiplying with factor of safety gives, 3353.3W (kurmi and Gupta, 2008). The power required for the drum filled with turmeric rhizome by overcoming the frictional force and other environmental condition is given by,

$P_t = \mathrm{P} + 0.1\mathrm{P}$ …………………………………………………………………………. (62)

$$\mathrm{Pt} = 3353.3\mathrm{W} + 0.1\ \times\ 3353.3\mathrm{W}$$

$$\mathrm{P} = 3688.63\mathrm{W}$$

$$P = 4.94 \sim 5hp$$

Power required for rotating the polisher shaft, polisher drum and turmeric rhizome inside the polishing unit through different speed mechanism were determined by Eqn. (60), (61) and (62) and found to be as 0.0159KW and 2229.86KW, respectively. The total power (P_t) required for operating the polisher and overcome friction and other environmental condition were determined using Eqn. (62). This was estimated to be 3688.63W (4.94hp). Therefore, a 5hp diesel engine with desired crank speed of 3000rpm was selected to drive the polishing machine during test and performance evaluation of the prototype.

3.3.8. Cost of production

The total weight of developed prototype material cost, production cost, manufacturing machine and production cost was determined as shown in Appendix H table 1,2,3, respectively. The costing of the machine was done in accordance to material costs; fabrication labor costs and machine costs.

3.3.8.1. Fixed cost analysis

Fixed costs are deprecation of the machine, interest of installments, insurance, and housing of a machine. Agricultural technology can be owned through duty free system according to regulation of reference letter of ME.30/58/9 dated 21/2/2012 of Ministry of Finance.

A. Depreciation cost

The level of mechanical wear may cause the worth of a particular machine to be somewhat above or below the average price of related machines when it is traded or sold. Depreciation is a value occurring from the, obsolescence, age and wear of polisher machine. Obsolence of older machine may occur during introduction of new technology suddenly and cause a sharp decline in its remaining value. According to Kepner et al., (2005) age and life of machine in hour are usually the most important factors in determining the remaining value of a machine described by the following formula.

$$D = \frac{P-S}{L} \quad \text{.......................................} \quad (63)$$

Where: D = depreciation per hour (ETB/hr.),

P = initial investment cost (ETB),

S = salvage value (10%) (ETB),

L = life of the machine in hours or year.

B. Interest

The remaining value of the machine in a given year can be assessed by interest on the machine. In case loan is used, the interest rate is known, for the purchase of demanded machine. But, if cash is used for the purchase of the particular machine relevant interest rate is used, this was when money is invested instead of machine procurement. The interest was determined by using equation (64) as follows

$$I = \frac{S+P}{2} \times i \quad \text{.......................................} \quad (64)$$

Where: I = interest per hour (ETB/hr.),

i = interest rate (%).

C. Insurance and housing

Srivastava et al., (2006) found difficulty of determining the exact value of the tax rate insurance and housing. The tax of agricultural technology has been lifted according to the proclamation written on 21/2/2012 from Ethiopian Ministry of Finance. Cost of insurance may be up to 0.25% of the capital cost of investment; and also the shelter cost as 0.5% of the capital cost of the investment of the machine.

3.3.8.2. Polisher operational costs

Operating costs of the machine includes repair and maintenance, fuel/electricity, labor wages and transportation costs. If the owner operates the machine, the labor cost is determined from alternative uses of the owner's time (Ojha & Michael, 2009).

A. Repair and maintenance cost

According to Kepner et al., (2005), illustrated repair and maintenance costs tend to increase with the size and complexity. Machine management and skilled operation reduces the repair and maintenance cost of the machine but always it is variable. Some costs will mostly be necessary to replace failed and/or worn parts for safety.

B. Fuel cost/electricity

Mechanical engines are used to change fuel energy into mechanical energy to help rotate the machine. The developed polishing machine uses diesel or electric motor by exchanging pulleys to attain recommended drum speed. Diesel engines are mostly recommended for their flexibility, availability and places of operation. Thus, it was used for testing during testing developed turmeric polishing machine.

C. Wage or labor cost

The cost of labor or the wage rate varies from place to place. In no case the typical charge for operation should be less than the community labor rate. One operator in the workshop is enough for the developed turmeric polisher.

D. Assumption made

Useful life of the machine was five year

Salvage value 10%

No. Of labor per day =1

Number of working hour 768hr. (Polishing can take place from April to July)

Interest rate = 10%

Taxes = assumed no taxes for agricultural technology

Rate of insurance = 0.25 of initial

Housing = 0.5% capital investment

Machine useful working time = three months after harvesting

The harvesting time of the product was = early March to late April

3.3.9. Data collection and considered variables

The performance of octagonal polishing machine was carried out on dried turmeric rhizome. It was done based on test results of polishing capacity (kg/hr), rotational speed (rev/min), operating time (minutes) per batch of kg, capacity of polisher (kg), the polishing percentage (%) and damage

3.3.9.1. Polishing time

Polishing process was dependent on the operation time. The time taken during polishing assumed to affect the percentage of turmeric polishing and describes the performance of machine. Therefore, the duration of operation during working was recorded and analyzed for effect on damage, capacity and percentage of polishing.

3.3.9.2. Drum speed

The drum was designed to have higher speed during polishing. According to Hoque & Hossain (2018), critical speed equation used, the drum speed was much less than the designed drum speed. The designed prototype works up to 95 rpm violating the formula stated.

3.3.9.3. Throughput capacity

The amount of polished turmeric received in total time taken for charging, polishing and discharging time were noted as machine/polisher output and calculated as (Shelake et al., 2019).

$$P_{output} = \frac{Wp}{tp+tL+tUl} = \frac{WP}{WT} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (65)$$

Where: P_{output} = Turmeric Polisher machine output (kg/hr)

W_T =Total time of polishing (hr)

t_P =Total time of polishing, hr;

t_L=Total time of Loading raw turmeric, hr;

t_{UL}= Total time of unloading polished turmeric, hr;

3.3.10. Performance evaluation of the polisher

3.3.10.1. Experimental design

Polishing time, speed and moisture content are the most important polishing parameters to control polishing quality and material removal rate. The Random Complete Block Design (RCBD) was used for an experiment to be done with a variation between the field (Ajay and Micah, 2017). The RCBD is the standard design for agricultural experiments where similar experimental units are grouped into blocks or replicates (Trudi G., 2010). The prepared produces (treatments) for polishing is divided into three different groups to see for any disparity so that observed variances are largely due to true differences between treatments.

3.3.10.2. Variables and data collection

Variables theoretical expectations about analysis of independent variables on the damage, polishing percentage and fuel consumption is particularly about designed and developed turmeric polishing machine. These variables are selected for performance evaluation based on the available reviewed literatures and personal experience. Thus, influences of these factors on damage, polishing percentage and machine fuel consumption were examined in the subsequent sections using linear regression methods. The independent variables are the speed of the polishing drum, operation time, moisture content of the product sample, and feed rate of 200 kg per batch. Drum speed, operation time, moisture content and color measurements are considered for performance evaluation. Drum speed was expressed in the number of revolution of drum in one minute while operation time is expressed by amount of time taken in minutes for one batch to be polished. During the experiment, the engine was set to operate at optimum engine operation and three different diameters of pulleys are used to attain required drum speed. The exact revolution of the drum was achieved by adjusting the position of fuel control throttle. The drum speed was measured using a non-contact tachometer that can measure angular speeds from 2 to 9999 rpm with accuracy of 0.10 rpm. Fuel consumption was articulated in amount of fuel consumed in liters during polishing of different samples. But, feed rate and color measurement was dropped from the analysis model while the rest three explanatory variables tracked against the outcome variables in the model. This is because of the absence of colorimeter for turmeric and difficulty in finding the instrument while feed rate is taken as constant.

A. Independent variables

- ✓ Time taken for polishing (min)
- ✓ Drum speed of the polisher (rpm)
- ✓ Moisture content of the turmeric rhizome

B. Dependent variables

- ✓ Damage in polishing (kg)
- ✓ Polishing percentage (%)
- ✓ Fuel consumed (ml.hr-1)

3.3.11. Performance testing and evaluation

3.3.11.1. Performance testing

The Performance of the prototype was tested based on machine parameters (polishing time, drum speed and moisture content) identified as treatments. A predetermined weight of 200 kg demonstrating one sample was fed into the drum at different drum speed (70, 85, 95 rpm) polishing time (15, 20, 25 min) and moisture content (at 11, 9 and 6%) for three replications. The drum speed was taken based previous literature review, and adjusted after trial and error for better performance of drum without centrifugation. It was designed to increase the drum speed for more contact of the product with drum wall.

3.3.11.2. Sample preparation

Dried turmeric previously available in Tepi Research Center was used for performance testing at the workshop level. The sample at higher moisture content was procured from local farmers for batch and performance testing.

3.3.11.3. Experimental procedure

The sample was weighed and prepared ready for each test before running the engine. The samples of three different moisture contents (6, 9 and 11%) were used for performance evaluation with drum speed and operation time. The sample is weighed and fed into the drum. Then the engine was started to run the drum. The polisher was tested on polishing time of 15, 20 and 25min along with drum speed of 70, 85, 95 rev/min on three replications. Both variables were recorded at each test for performance evaluation. The polished turmeric was collected through outlet door on sliding collector and weighed at each drum speed and polishing time.

3.3.11.4. Performance Criteria

The measured quantity of turmeric was loaded in to the polishing drum up to ¾ of the full capacity. It was noted as feed capacity of the batch to allow free movement of turmeric in the drum. After polishing turmeric on three different moisture content and speed and polishing time, weight after polishing, damage, and fuel consumed and colour was recorded for performance testing. The quantity of polished turmeric received in total time, including feeding, polishing and discharging time, is noted for machine capacity calculation.

A. Polishing capacity

The polishing capacity of the machine was determined from the amount of turmeric rhizome polished in a total time taken using eqn. (66) below.

$$\text{Polishing Capacity} = \frac{W_P}{Tt} \quad \ldots\ldots (66)$$

Where: Polishing capacity (kg/hr)

W_p = weight of polished turmeric (kg) and

T_t = Total time required for polishing on batch (hr)

B. Damage in polishing

The damaged rhizome was estimated by adding waste and turmeric lost because of breakage and size. To minimize the loss, the normal turmeric loss because of size through wiremesh opening was considered during design of the polisher machine. In contrary to this, the broken turmeric lost though the drum opening was considered as damage. The total weight of damaged turmeric by breakage, waste and loses was calculated by the following formula.

Damage = waste + lost turmeric (including broken)

C. Polishing percentage

The mass of turmeric to be lost during polishing in per batch from an input quantity was taken as polishing percentage and calculated by eqn. (67) (Shelake et al., 2018; Dilip et al., 2021).

$$\text{Polish percentage} = \frac{W_r - W_p}{W_r} \times 100 \qquad \text{…………………………………………..…………... (67)}$$

Where: W_r =Weight of raw turmeric, kg and;

W_p= Weight of polished turmeric, kg.

D. Fuel consumption

Fuel consumed while polishing the rhizome at a given feeding rate, drum speed and time was recorded by using measuring cylinder. Firstly, the diesel Engine was filled with fuel, then after running the drum for recommended different speed.

3.3.12. Statistical analysis

Data collected were subjected to analysis of variance using the statistical procedure as described by (Rudolf et al., 2006). IBM SPSS Statistical software version 21 was employed for the analysis. When the treatment effects were determined to be significant, a linear regression model was utilized to articulate the probability function describing the impact of predictor variables on the dependent ones. Multivariate analysis was used to further analyze and represent graphically.

A regression model specifies a relation between a dependent variable Y and certain explanatory variables X_1. X_K a linear model sets

$$Y = \beta 0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_K X_K + \varepsilon \text{……………………………………………………………….(68)}$$

Where, ε (epsilon) is the error term. Y is dependent variable (damage during polishing, polishing percentage and fuel consumption of the machine engine during polishing) and X is corresponding values such as time, speed and moisture content.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Physical and Mechanical Property of Turmeric Rhizomes

4.1.1. Physical properties

The physical properties such as length, width, and thickness, sphericity, geometric mean diameter, surface area, bulk density, porosity, angle of repose and mechanical properties i.e. static and dynamic coefficients of friction, angle of internal friction and rupture force of turmeric rhizome were calculated and discussed below.

The average length of dried turmeric rhizome was 34.25, 35.43, and 35.22mm on stated moisture content of the rhizome. This was because of the shrinking property of turmeric after losing moisture. However, there is slight significant trend for width (11.38, 12.85 and 13.21 mm) and thickness (11.38, 12.85 and 13.21 mm) among different moisture contents. The surface area of the rhizome was found to increase with the increasing in moisture content as described in the table below. Geometric mean diameter (23.12, 24.77 and 28.53mm), showed an increasing trend with the increase in length, width and thickness of rhizomes.

The sphericity of the rhizome was 0.324, 0.31, and 0.305 at moisture contents of 6, 9 and 11% (wb). The sphericity of turmeric rhizome increases as the moisture content decreases. It may be due to the fact that turmeric rhizome bends towards breadth as it becomes loosing moisture. It was not considered symmetrical to the shape of the sphere. The average surface area of turmeric rhizome increased from 1159.5mm^2 to 1589mm^2 with increasing in moisture content. The result was because of increasing body surface width with increase in moisture amount.

Bulk density was decreased with increase in moisture content. It was an important property used in designing of drum volume and discharge opening door of turmeric polishing machine. Bulk densities of turmeric rhizome were 526.8, 534.52 and 539.5 kg/m3 for moisture content of 11, 9 and 6% respectively. This behavior of decrease in bulk density might be due to the fact that volume expansion of the sample will occur as a result of increase in moisture content. As the result, the high moisture sample occupies more space than the less moisture product which leads to increased volume and decreased mass of the sample. This may be due to increase in volumetric expansion in the sample is higher than the weight with increase in moisture content. The average porosity of dried turmeric rhizome calculated at 6, 9, 11% moisture content were found to be 58.474, 58.518 and 58.59 respectively. The calculated porosity for relevant experimental sample indicates slight decrease with decreased turmeric rhizome moisture content. The trend was found to be closer to the findings of Poornima et al. (2019). The angle of repose of turmeric rhizome increased from 35.89, 36.63 and 37.44 as its moisture content increased from 6, 9 and 11% respectively. This may be due to the coarser nature of the dried turmeric surfaces, and hence the surface area.

4.1.2. Mechanical property of turmeric rhizome

Coefficient of static friction of the turmeric product was 0.721, 0.743, and 0.758 for galvanized steel metal and (0.862, 0.834, 0.811) for plywood. The static coefficient of friction for turmeric samples increased with the moisture increase (6-11%w.b.) for galvanized structural surfaces and decrease for plywood. There are several ground product factors affecting the static coefficient of friction *eg* stickiness product and its cohesiveness. As it is stated in table below there is a significant difference between GSM and PLW. It was observed that that the static coefficient of friction was the highest on the plywood surface followed by galvanized iron sheet surfaces.

Dynamic coefficient of friction was 0.240, 0.252, and 0.271 at the same moisture content pointed above. As illustrated in the table 4.1 the static coefficient friction was higher than kinetic coefficient friction for moisture content tested.

Table 4. 1. Summarized physical and mechanical property of turmeric rhizome

Property parameters	Value across moisture content		
	6%	9%	11%
Length	34.25	35.43	35.22
Width	11.38	12.85	13.21
Thickness	8.37	8.89	9.25
Sphericity	0.324	0.31	0.305
Geometric mean diameter	23.12	24.77	28.53
Surface area	1159.5	1408	1589
Bulk density	539.5	534.52	526.8
Porosity	58.474	58.518	58.59
Repose Angle	35.89	36.63	37.44
Coefficient static Friction (GSM)	0.721	0.743	0.758
Coefficient static Friction (PLW)	0.862	0.834	0.811
Coefficient of dynamic friction	0.241	0.254	0.273
Angle of internal Friction	88.4	88.44	88.47
Rupture Force	185	128	93.05

The angle of internal friction was 88.43 with almost no differences across change in moisture contents. Rupture force of turmeric rhizome was 1839,128 and 93.05 at stated moisture content. The obtained data on the physical and mechanical property of turmeric rhizomes was summarized as follows.

4.2. Performance Evaluation of Turmeric Polishing Machine

The investigations of polishing with designed drum were conducted using dried turmeric rhizome at different drum speed and time ranges. The interval of drum speed taken was 70, 85, 95 rpm with a time interval of 15, 20, 25 minutes. On the other hand polishing turmeric rhizome depends on the percentage of moisture content in the product. During the investigation it was considered by taking a product on different moisture content. The effect of drum speed and time interval of operation and moisture content of the product on the performance of the prototype machine was determined through damage (waste and lost, breakage), polishing efficiency and polishing percentage and fuel consumption (Fc).

4.2.1. Polishing capacity

The developed turmeric polishing machine processes 200 kg of turmeric in 25 min. The time required to load the product is 5minute while the time to unload the product is 3minute.

Table 4. 2. Time required during polishing one batch

Operation	Time taken
Loading	5min
Polishing	25min
Unloading	3min
Total Time	33min

The total time taken to polish 200 kg of turmeric is the sum of loading, polishing and unloading turmeric per one batch. Thus, the capacity of the polisher calculated by equation (88) above is 364kg/hr.

4.2.2. Damage during polishing

4.2.2.1. Effect of speed, operation time and moisture content on damage

These studies were conducted to determine if the selected parameters could influence the damage of product during polishing. During testing, different speed, operation time, and moisture content was taken for performance evaluation. According to the analysis the influence of predictor's i.e. speed of drum; operation time and moisture content of product have influences on the damage of turmeric rhizome during polishing machine operation. Both drum speed and moisture content have direct relationship to damage at strong correlation of 71.8 and 0.538 correlations respectively. As shown in the table 4.3 the effect of variables were directly proportional to polished turmeric damage. As drum speed increases the damage increases. On the same way, as the operation time and moisture content increases the amount of product damage in the drum increases. The result revealed that for every one rev/min increase in drum speed there will be 1.253 kg increase on turmeric damage during polishing. On the other ways for every 1% increase of product moisture content there will be 0.373 kg increase of product damage. Furthermore, the relationship of drum operation time with damage was also directly proportional damage with slope value coefficient of 0.519. This means that for every one minute increase of operation time there will be 0.519 kg of increase in damage. Speed of operation has higher influencing coefficient that other because the higher contact of product with abrasive surface in the drum during higher speed. The analysis predictor variables on effect of turmeric damage during polishing depicted a higher significance at ($P < 0.001$) on all parameters.

Table 4.3. Likelihood estimates of linear regression function for effect of predictors on the damage

Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Speed	1.253	0.119	0.718	10.525	0.000***
Time	0.519	0.119	0.297	4.359	0.000***
Moistcontent	0.373	0.047	0.538	7.891	0.000***
(Constant)	-1.510	0.601		-2.511	0.019**

NS= Not statistically significant, * = significant at 10%, ** = significant at 5%, *** = significant at 1% level.

The combination of the variables influences amount of damage during performance evaluation of turmeric polishing machine. The ANOVA and model summary indicated in the table below revealed that the overall output of the regression model was significant at $P < 0.001$.

Table 4.4. ANOVA, effect of predictor variables on damage

Variables	Sum of Squares	df	Mean Square	F	Sig.
Regression	48.978	3	16.326	64.017	0.000
Residual	5.866	23	0.255		
Total	54.844	26			
R^2	0.893				
Std. Error of the Estimate	0.505				
Durbin-Watson	0.367				

Dependent Variable: Damage, Predictors: (Constant), moist content, time, speed

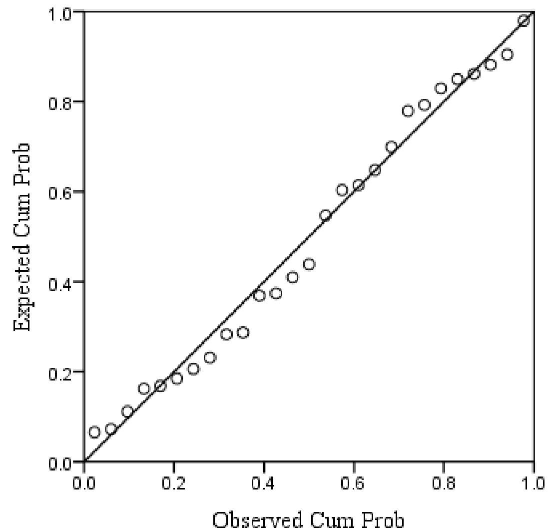


Figure 4.1. Normal P-P Plot of Regression Standardized Residual of Dependent Variable: damage

4.2.3. Polishing Percentage

Effect of speed, duration of operation and moisture content on percentage of polishing

These studies were conducted to determine if the selected parameters could influence the percentage of polishing. The evaluation of polishing machine performance with drum speed (70 rpm, 85 rpm, 95 rpm), time (15 min, 20 min, 25 min), and moisture content (6%, 9%, 11% mc on wb) of the product on polishing percentage was investigated. Based on the performance evaluation of turmeric polisher machine the influence of speed, time of operation and moisture content of product on the performance of the turmeric rhizome all parameters have significant effect. The regression results show that the three predictors were accounted for 77.9% of the variance in the percentage of polishing rhizome collectively. Both drum speed and moisture content have direct relationship to damage at strong correlation of $R^2 = 0.893$. As shown in the table 4.3 the effect of variables were directly proportional to turmeric polishing percentage increases with increase of predictor parameter value. As drum speed increases the polishing percentage increases.

On the same way, as the operation time and moisture content increases the polishing percentage increases. The result revealed that for every 1 rev/min increase in drum speed there is 96.4% increase on turmeric polishing machine. On the other hand for every 1% increase of moisture content there is 17.3% increase of percentage of polishing. Furthermore, the relationship of drum operation time with polishing percentage was a direct proportional with a correlation coefficient of 45.3. This indicates that for every 1 min increase of operation time there is 45.3% increase of polishing percentage. The increment of polishing percentage was determined by drum operation speed and operation time and moisture content respectively. Speed of operation has higher influencing coefficient than others because the higher contact of product with abrasive surface in the drum during higher speed at a correlation of 0.821. The analysis predictor variables on effect of turmeric polishing percentage during machine operation depicted a higher significance at ($P<0.001$) on all parameters.

Table 4.5. Likelihood estimates of linear regression function for effects of speed, time, and moisture content on the polishing percentage

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Time	0.453	0.074	0.386	6.151	0.000***
Speed	0.964	0.074	0.821	13.079	0.000***
Moisture content	0.137	0.029	0.293	4.666	0.000***
(Constant)	-.779	0.372		-2.092	0.048**

Dependent Variable: polishingper, NS= Not statistically significant, * = significant at 10%, ** = significant at 5%, *** = significant at 1% level.

Considering the unique individual contributions of the predictor variables, the result shows that there were significantly high increments of polishing percentage with increase of drum speed, time elapsed and decrease of product moisture content at $P < 0.01$ as shown in the table above.

Table 4.6. ANOVA, effect of predictor variables polishing percentage

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	22.551	3	7.517	76.884	0.000
Residual	2.249	23	0.098		
Total	24.800	26			
R^2	0.909				
Std. Error of the Estimate	0.313				
Durbin-Watson	1.198				

Predictors: (Constant), moisture content, time, and speed

From the analysis it was indicated that the least polishing percentage resulted on lower drum speed and time elapsed during polishing. The combination of the variables influences amount of damage during performance evaluation of turmeric polishing machine. The ANOVA and model summary indicated in the table 4.6 revealed that the overall output of the regression model was significant at $P < 0.001$. The 1.198 coefficient of Durbin Watson here also shows the automatic relationship of predictor variables with dependent variable directly.

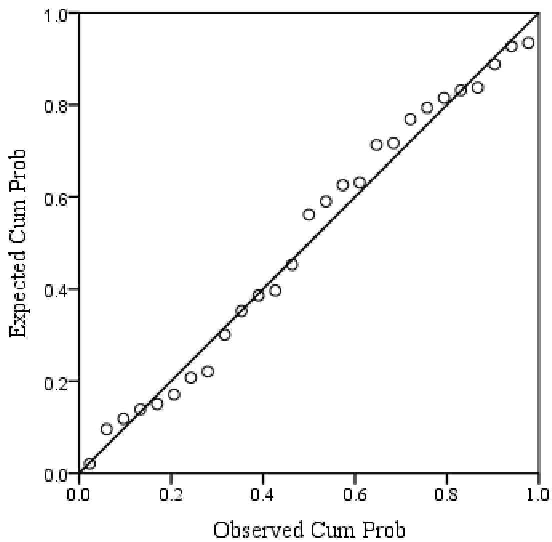


Figure 4.2. Normal probability plot of regression standardized residual of dependent variable for polishing percentage

4.2.4. Fuel Consumption

4.2.4.1. Effect of speed and duration of operation and moisture content on fuel consumption

The amount of fuel consumed is influenced by speed and duration of operation. Fuel consumption increases with increasing speed and operation time. Based on the regression coefficients, both speed and time found to make the greatest contribution to the fuel consumption of the polisher machine engine with a direct and strong correlation of $R^2 = 0.993$. The slope value of 0.006 indicates that for every 1 rev/min increase of drum speed there is 0.006 L/min increase of fuel consumption of machine engine during operation. Additionally, for every one unit increase of machine operation time there will be 0.160 L/min increase of fuel consumption of machine engine. As indicated in table 4.4 below the analysis of variances, on fuel consumption of the turmeric polishing machine shows that duration of operation and drum speed had highly significant effects on the fuel consumption of the polishing machine at ($P < 0.01$) and ($P < 0.05$) respectively. But moisture content was insignificant because of the reason that it does not has relationship with engine operation during polishing. Time of operation during polishing has higher influencing Pearson correlation coefficient of 0.996 on fuel consumption. This revealed that fuel consumption will be more affected by increasing time taken during operation. Drum speed has lower effect during operation because, the higher the speed the lower the torque of drum shaft exerted on the polishing machine shaft.

Table 4.7. Likelihood estimates of linear regression function for effects of speed and time of operation and moisture content on the machine engine fuel consumption

Dependent Variables	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Speed	0.006	0.003	0.038	2.237	0.035**
Time	0.160	0.003	0.996	58.573	0.000***
Moisture content	-0.001	0.001	-0.016	-0.916	0.369NS
(Constant)	0.312	0.014		22.576	0.000***

Dependent Variable: fuel consumption, NS= Not statistically significant, * = significant at 10%, ** = significant at 5%, *** = significant at 1% level.

Considering the unique individual contributions of the predictors, the result shows that there were significantly high increments of damage with increase of drum speed, time elapsed and decrease of product moisture content at $P < 0.01$ as indicated in the model summary (ANOVA) in the table below

Table 4.8. ANOVA, effect of predictor variables fuel consumption

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.462	3	0.154	1145.552	0.000b
Residual	0.003	23	0.000		
Total	0.465	26			
R^2	0.993				
Std. Error of the Estimate	0.0116				
Durbin-Watson	2.530				

a) Dependent Variable: fuel consumption, b) Predictors: (Constant), moisture content, time, speed

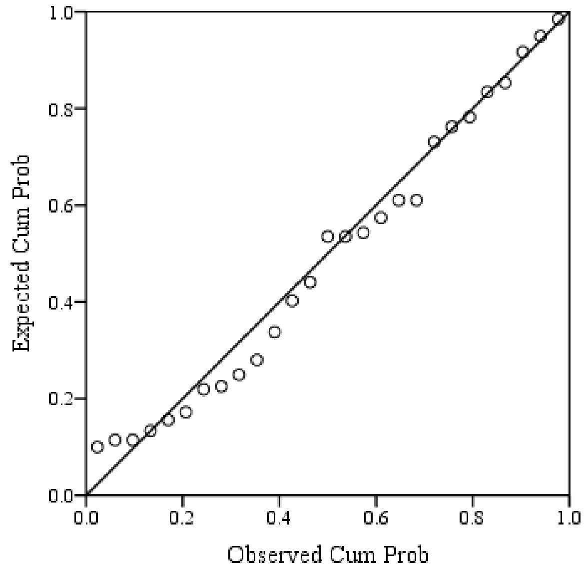


Figure 4. 3. Normal probability plot of regression standardized residual of dependent variable for fuel consumption

Multivariate Analysis for variables

During performance evaluation test the influence of duration of time, speed and moisture content of product on the performance of the turmeric rhizome was estimated. The effect of speed and moisture was directly proportional to damage of the polished turmeric (Appendix D, figure 1,). As the moisture content and drum speed increases the amount in damage increases. On the same way, increase of predictor variables increases polishing percentage (Appendix D, figure 2). As the graph below shows that the drum speed and time increases the percentage of polishing percentage increases. Polishing percentage was indicated in terms of loss, breakage and waste resulted during polishing. Additionally, as the moisture content of turmeric rhizome increases the polishing percentage increases. This will be because, the decrease of product hardness as the moisture content rises. Thus, it causes more damage of finger rhizome form the mother one. The least percent tuber mechanical damage of 3.12% was observed at drum speed of 70 rpm, 15 minute and 6% moisture content and with a feed of 200 kg per batch. Maximum percent turmeric polishing of 4.98% was occurred at drum speed of 85 rpm and polishing time of 25minutes. The graph indicated that at the 85rpm of drum speed maximum polishing efficiency occurs.

The percentage of polishing rhizome was increased by increasing the speed intervals from 70, 85 to 95 rpm. But with the decrease of moisture content, the analysis shows that there was a decrease on amount of damage. The maximum value of damage percentage of turmeric rhizome was 4.98% at moisture content of 11 on (wb) and speed of 85 rpm, while the minimum value exists at 70rpm and moisture content of 6%. At 95 rpm of drum speed the polishing percentage slightly decreases. This is because the happenings of centrifugation of turmeric rhizome in rotating drum. This results in decrease of dynamic frictional force between drum and turmeric product in the drum. Slight contact and movement of product with drum without frictional existence exists at a time.

The combination of the variables influences fuel consumption during performance evaluation of turmeric polishing machine. It was observed that fuel consumption increased as drum speed increased from 70 rpm to 95 rpm km/hr alongside with 15 minute to 25minute (figure 4.6)
The result during performance evaluation revealed that higher polishing percentage was on 85 drum speed, 25 min of operation and 9% mc of the rhizome. It was at which the higher polishing percentage and optimum damage was seen during polishing and taken as optimum machine (Appendix D). At this operation stage product looks better on smoothness, brightness and looks like olive yellow color.

Limitation

Colour measurement for percentage of polishing was an important parameter despite the limitation of the study because of the absence of colour meter instrument required to measure during performance testing.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

Dried turmeric rhizome has a rough dull outer surface with scales and dirty roots on outer surface. Dirty clay and impurities on the surface of the turmeric rhizome were a major concern for the users. It was valued for its cleanness and yellowish color and bright smooth surfaces. Polishing the outer surfaces by mechanical rubbing improves the appearance of turmeric rhizome. Thus, the research study aims to help the smallholder farmers by developing mechanical device empowered to polish turmeric rhizome. The 5hp powered turmeric polishing machine capable of polishing 200 kg of turmeric suitable for smallholder farmers and small-scale enterprises was designed and developed. Easiness, simplicity, capacity, quality and women friendly factors are considered during design and development. It can be easily assembled and disassembled during repair and requires only a single person to operate. It uses simple mechanism which found to be simple and cost effective for maintenance. The machine drum was designed to enable turmeric polishing and decreasing food contamination.

Therefore, the operating condition and performance were assessed based on predictor variables during test made and conclusions are derived from the analysis observation. The statistical analysis carried out indicated that drum speed, operation time, and m.c influences damage, polishing percentage and fuel consumption at different significance level. At the drum speed of 85 rpm the machine performance parameters indicated peak value. At this point of machine operation time and drum speed, the recorded loss was higher. Polishing percentage and damage was better with smooth, bright and olive yellow color appearance. Damage of turmeric rhizome was optimum and deceases at decreasing moisture and increases through increasing all parameters. Considering the unique individual contributions of the predictors, the result shows that there were significantly high increments of damage with increase of drum speed, time elapsed and decrease of product moisture content at $P < 0.01$ and with a DWC of 0.367 indicating predictors auto correlation with damage. Polishing percentage has auto correlation with independent variables at DWC coefficient of 1.198. This indicates that increase of predictor variable increases polishing percentage. The damage of product and polishing percentage was seen as higher on 85 rpm and become declining with the increase of speed because of existence of centrifugation in the drum. This means that the product starts to move with the drum without frictional resistance so that decrease in percentage of polishing takes place.

Based on the results obtained, it was concluded that the performance of the designed and developed prototype of the machine is very much acceptable with the user and high prospect recommending for smallholder farmers and other interested parties.

5.2. Recommendations

- One of the limitations of this study was the absence of color measurement of the polished product during performance evaluation. The evaluation was under taken with manual evaluation of experienced person.
- Development of turmeric processing (drier-polisher) in a single process is very useful to save time and minimize the loss of this useful product is recommended.
- It is important to consider the design of polisher machine with auger for lifting and packing purposes.
- The design of turmeric polishing machine with cleaner, loader and packing to the appropriate packaging materials is recommended.

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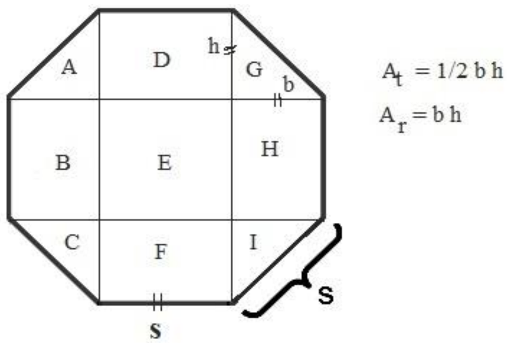
APPENDIXES

Appendix A: Durim side side calculation

Area and Volume of Octagonal Drum



$$s^2 = b^2 + h^2$$
$$s^2 = h^2 + h^2$$
$$s^2 = 2h^2$$
$$h^2 = \frac{1}{2}s^2$$
$$h = \sqrt{\frac{s^2}{2}} = \frac{s}{\sqrt{2}}$$

Area of Regular octagon

The total area of the octagonal diagram above is the sum of area of triangles and rectangles as shown above.

$A_T = A_E + A_{BFHD} + A_{ACIG}$ ………………………………………………..…………………………………… (1)

Area of triangle is given by the equation (2) as follows

$A_{ACIG} = \frac{1}{2}\, b \times h$ ……………………………………………………………………….……..…..…………………… (2)

So the total area of triangles in the diagram is

$A_{ACIG} = 4(\frac{1}{2}\, b \times h)$

Because the two sides of triangle are equal, i.e. equilateral triangles, then

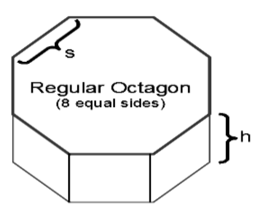
$A_t = 4\left(\frac{1}{2} b \times h\right) = 2h \times h = 2h^2$ …………………..………………………..…….…....……………………. (3)

$A_{BFHD} = s \times h$ ……………………………………………………………………………………..………………. (4)

Since, the available rectangles except "E" is equal, then area of four rectangles are equal, then

$A_{BFHD} = 4 \times s \times h$ ………………………..…………………………………………………….……..……… (5)

Total area is equal to



$A_{total} = s^2 + 2h^2 + 4sh$

$A_{total} = s^2 + 2\left(\frac{s}{\sqrt{2}}\right)^2 + 4s\left(\frac{s}{\sqrt{2}}\right) = s^2 + s^2 + \frac{4s^2}{\sqrt{2}}$

$A_{total} = 2s^2 + 2s^2\sqrt{2}$

$A_{total} = 2(1 + \sqrt{2}) \times s^2$ ……………………………………………………..…………………...………… (6)

$V = 2(1 + \sqrt{2})s^2 \times h$ ……………………………………………………………………….....……………. (7)

Appendix B: Machine weight calculation

Table 1. Basic number of bearing and capacity of bearing

Bearing No.	Bore	Outside dia	Width (mm)	Basic capacity in KN			
				Single row deep groove ball bearing		Single row angular contact ball bearing	
				Static	dynamic	Static	Dynamic
202	15	35	11	3.55	6.10	3.75	6.30
203	17	40	12	4.4	7.5	4.75	7.8
204	20	47	14	6.55	10	6.55	10.4
205	25	52	15	7.1	11	7.8	11.6
206	30	62	16	10	15.3	11.2	16
207	35	72	17	13.7	20	15.3	21.2
208	40	83	17	16	22.8	19	25
209	45	91	18	18.3	25.5	21.6	28

Source: (Kurmi and Gupta, 2005)

Table 2. Weight calculation of the machine

No	Components	Quantity	Length(m)	Width (m)	Thickness(m)	Unit mass (kg)	Total Mass (Kg)
1	Frame	1	50x2350mm			25	17
2	Pulleys	Engine Pulley				5.12	5.12
		Gearbox pulley				3.56	3.56
		Drum pulley				4.32	4.32
3	Speed reducer Gearbox	1				7.1245	7.1245
4	Drum Shaft	1	1.65		0.04	14.65	14.65
5	Engine seat	1				9.67	9.67
6	Bearings	2				0.73	1.46
7	Machine drum	Drum cover				10.595	21.19
		Door				5.48	5.48
		Polishing unit	Wire mesh			1.689	1.689
			Expanded metal wire				3.892
			Flat iron				29.47
			Perforated stainless steel				5.7
		Shaft attachment				3.08	6.16
		Handle				0.05	0.1
		bushing				3.45	6.9
		Bolts & nuts (96)				0.035	3.36
8	Engine	1				20.123	20.123
9	Belts	2				0.28	0.56
10	Collector (Cleaner)	Sheet metal					2.5
		Frame					3
	Rivets	40				0.025	0.25
	Total						173.2785

Appendix C: Linear regression analysis on the factors affecting damage, polishing percentage and fuel consumption

1. Polishing percentage

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.954[a]	.909	.897	.31268	1.198

a. Predictors: (Constant), moistcontent, time, speed
b. Dependent Variable: Polishperc

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	22.551	3	7.517	76.884	.000[b]
	Residual	2.249	23	.098		
	Total	24.800	26			

a. Dependent Variable: Polishperc
b. Predictors: (Constant), moistcontent, time, speed

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.779	.372		-2.092	.048
	speed	.964	.074	.821	13.079	.000
	time	.453	.074	.386	6.151	.000
	moistcontent	.137	.029	.293	4.666	.000

a. Dependent Variable: Polishperc

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	1.9114	5.4290	3.6930	.93131	27
Residual	-.69582	.53099	.00000	.29409	27
Std. Predicted Value	-1.913	1.864	.000	1.000	27
Std. Residual	-2.225	1.698	.000	.941	27

a. Dependent Variable: Polishperc

2. Damage

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.945[a]	.893	.879	.50500	.367

a. Predictors: (Constant), moistcontent, time, speed

b. Dependent Variable: Damage

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	48.978	3	16.326	64.017	.000[b]
	Residual	5.866	23	.255		
	Total	54.844	26			

a. Dependent Variable: Damage

b. Predictors: (Constant), moistcontent, time, speed

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.510	.601		-2.511	.019
	speed	1.253	.119	.718	10.525	.000
	time	.519	.119	.297	4.359	.000
	moistcontent	.373	.047	.538	7.891	.000

a. Dependent Variable: Damage

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	3.0197	8.4292	5.7867	1.37251	27
Residual	-.76301	1.03076	.00000	.47498	27
Std. Predicted Value	-2.016	1.925	.000	1.000	27
Std. Residual	-1.511	2.041	.000	.941	27

a. Dependent Variable: Damage

3. Fuel consumption

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.997[a]	.993	.992	.01159	2.530

a. Predictors: (Constant), moistcontent, time, speed

b. Dependent Variable: fuelconsump

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.462	3	.154	1145.552	.000[b]
	Residual	.003	23	.000		
	Total	.465	26			

a. Dependent Variable: fuelconsump

b. Predictors: (Constant), moistcontent, time, speed

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.312	.014		22.576	.000
	Speed	.006	.003	.038	2.237	.035
	Time	.160	.003	.996	58.573	.000
	moistcontent	-.001	.001	-.016	-.916	.369

a. Dependent Variable: fuelconsump

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.6268	.9639	.7952	.13324	27
Residual	-.01485	.02515	.00000	.01090	27
Std. Predicted Value	-1.264	1.267	.000	1.000	27
Std. Residual	-1.282	2.170	.000	.941	27

a. Dependent Variable: fuelconsump

Appendix D: Graphical representation of multivariate effect of predictor variables on dependents variables

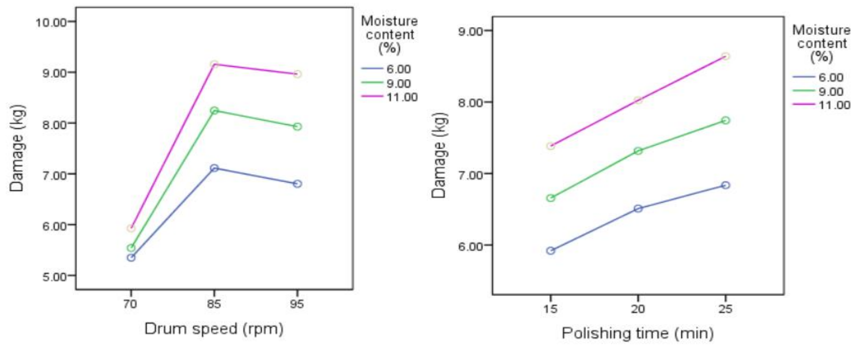


Figure 1. Effect of a) Drum speed and moisture b) Time and moisture content on damage

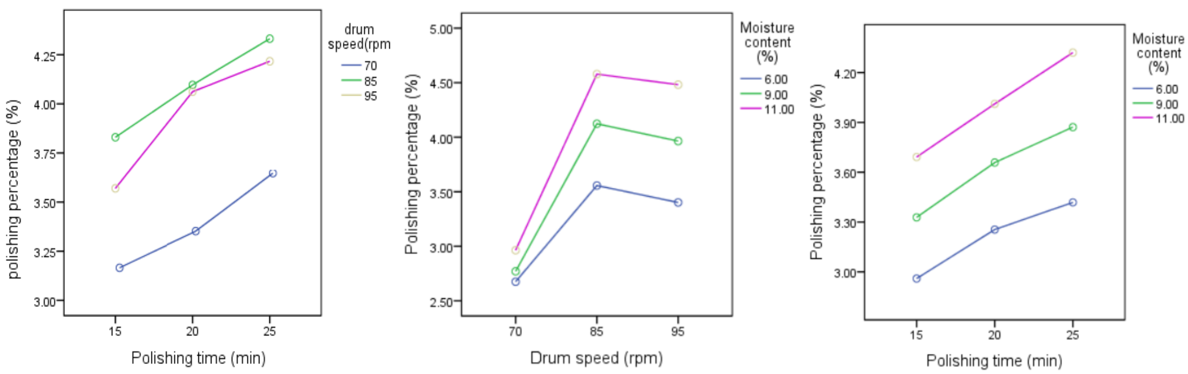


Figure 2. Combined effect of a) time and speed b) speed and moisture content c) time and moisture content on polishing percentage

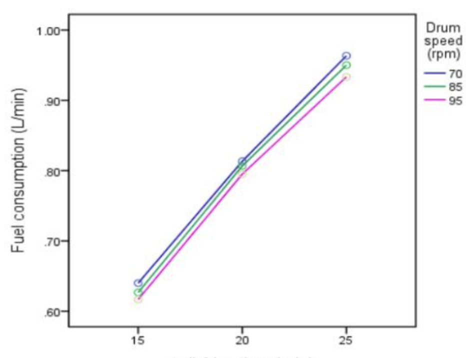


Figure 3. Effect of speed and duration of operation on fuel consumption

Appendix: E. Exported turmeric by a) table b) graph

Table 1. Weight of the product and value earned in USD

Years	2005	2006	2007	2008	2009	2010	2011	2012
Weight	3753.51	2531.88	4450.11	5166.9	3414.03	4994.97	2930.24	2369.01
Value(USD)	23,31986	1,553,686	3,412,541	4,46,2840	3,392,389	4,441,587	2,435,478	1,336,799

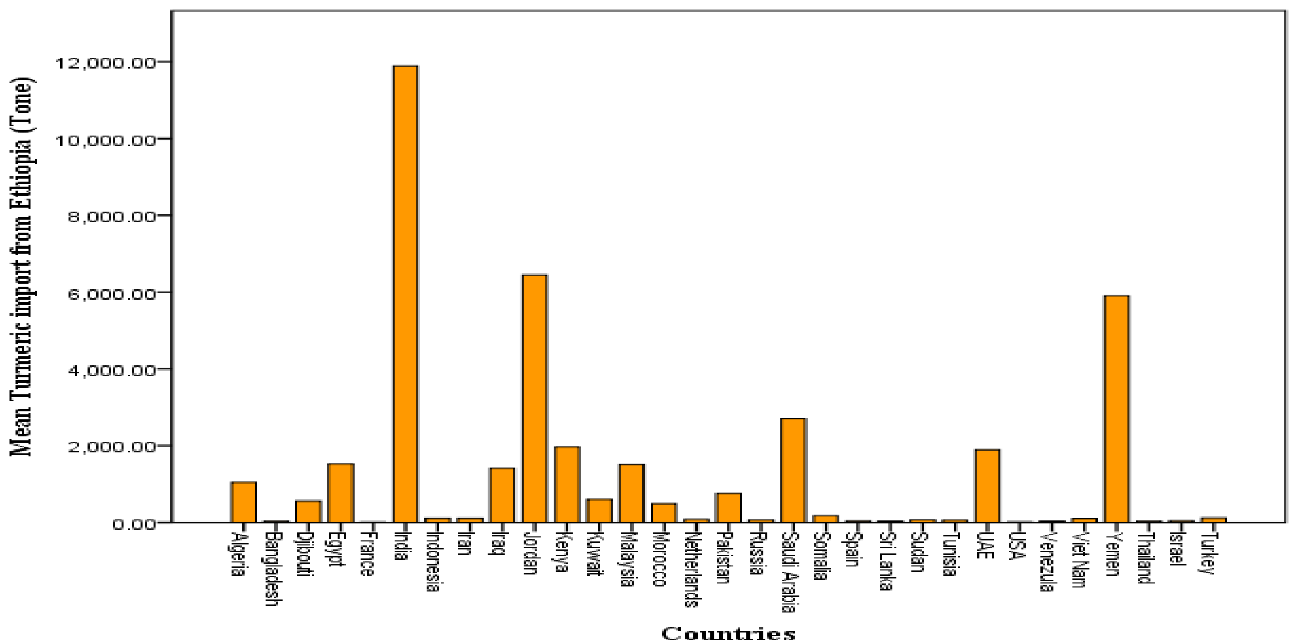
Source: ECTA (Ethiopian Coffee and Tea Authority), 2021

Table 2. Turmeric Production in Ethiopia in the Last Five Years

Turmeric	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Area hectares in 5 years	Xxxx	4031	5041	5971	6616	7277
Production in Tons in 5 years	6260.0	16607.4	15526.3	26809.8	24479.2	25264.9

Source: ECTA (Ethiopian Coffee and Tea Authority), 2021

Turmeric production in the country is increasing in the past five years with dramatical increase of demand in production and consumption in the country.



Source*:* Ethiopian Coffee and Tea Authority, 2021

Figure: Countries importing turmeric product from Ethiopia

Appendix F: Size of and description of polishing unit

External wire mesh

As of measured by digital balance having area of, A= L x W, 0.3m x 0.5m, with a mass of 0.09 kg. It was directly measured using digital balance. Then, Area of one side is determined by using Eqn. (24)

$A = s \times h$

$\mathrm{A = s \times h \ = \ 0.305m \times \ 1.1m}$

$A = \ 0.3355\, m^2$

Area of 8 sides is calculated by using the following Eqn. (24)

$\mathrm{A = 8(s \times h)}$

$A = \ 8\ (0.3355) m^2 \ = 2.684 m^2$

Mass of external mesh wire

$$\mathrm{m} = \frac{2.684\mathrm{m}^2 \times \ 0.09\mathrm{kg}}{0.143\mathrm{m}^2} = 1.689\mathrm{kg}$$

Weight of metal wire, $\mathrm{w = m \times g = 1.689kg \times \ 9.81m}/s^2$

$$\mathrm{w = 16.57N}$$

Weight of drum cover

Area of drum cover is equal to, area of octagonal face, at the two ends side of the drum and calculated as follow

$A = 2\left(1 + \sqrt{2}\right)s^2$, width of one side is equal to, s=0.305m

Then $A = 2\left(1 + \sqrt{2}\right)(0.305)^2$

A= 0.449m^2

$V \ = \ surface\ area\ x\ thickness\ of\ metal\ sheet$

$V = 0.449\mathrm{m2} \ \times \ 0.003m$

$\mathrm{V = 0.001347m^3}$ two side volume is equal to,

$\mathrm{V = 0.001347m^3 \times \ 2}$

$\mathrm{V = 0.002694m^3}$

The mass of steel metal sheet having 3mm thickness on both ends of the octagonal rotating drum is calculated using the eqn. (8),

$\rho = \frac{m}{v}$

$Density\ of\ carbon\ steel\ sheet, \rho = 7866\ kg/m^2$

Mass of metal sheet is calculated by density ratio

$\rho = \dfrac{m}{v}, then\ \ m = pv$

Where: m = mass of steel metal sheet

v= volume of the steel metal sheet

ρ = density of metal steel sheet

$m = 7866\,\frac{kg}{m3}$ x $0.002694m^3$

$m = 21.19kg$

Weight of metal sheet

$w = mg = 21.19kg \quad \times 9.81m/s2$

$w = 207.87N$

Mass of flat iron bars used on outermost part of the drum to add the strength of the drum.

A flat iron with of length 23.7m long of 0.004m thickness and 0.05m width were used.

L= 16 × 1100mm + 8 × 765mm

L=23720mm

A= 23720mm × 50mm

A= 1,186,000mm2

V=1,186,000mm ×4mm

V= 4,744,000mm3

Mass is calculated from density, product of density and volume,

$m = \rho v = 7866\,\frac{kg}{m3} \times\ 0.004744m3$

$m = 37.316kg$

$w = mg = 37.316kg\ \ \times\ 9.81\,\frac{m}{s^2}$

$w = 366.07N$

Mass of expanded metal wire

The actual mass of 2m x1m expanded metal wire was measured by using the digital balance. The dimension of the expanded metal wire mesh = 2m x 1m size. The mass of expanded metal wire having $2m^2$ area is 2.9 kg. Area of one side is as follows

$A = sxh$

$A = s \times h = 0.305m\ \times\ 1.1m$

$A =\ 0.3355\ m^2$

Area of 8 sides is calculated by

$A = 8(s \times h)$

$A = 8\ (0.3355)m^2 = 2.684m2$

Weight of required expanded metal sheet wire of 1.5 mm thickness is

$w = m \times g, \quad w = 2.9kg \times 9.81\frac{m}{s^2} = 28.449\frac{kgm}{s2} = 28.449N$

The size of the required weight of expanded metal wire is equal to area of expanded metal wire used for constructing the drum.

$\mathrm{w} = \frac{2.684\mathrm{m2} \times 28.449\mathrm{N}}{2\mathrm{m}^2} = 38.18\ \mathrm{N}$

$\mathrm{w} = \mathrm{mg} = 38.18\ \mathrm{N}$

$\mathrm{m} = 3.892\mathrm{kg}$

Mass of rivets

It was assumed to use forty rivets, the mass of these rivets are,

$\mathrm{m} = 40\ \text{rivets} \times 0.02\mathrm{kg}$

$\mathrm{m} = 1.2\mathrm{kg}$

$\mathrm{w} = 1.2\mathrm{kg} \times 9.81\mathrm{m}/s^2$

$\mathrm{w} = 11.77\mathrm{N}$

Mass of bolts and nuts

The number of bolts and nuts used where 95, then the mass of these bolts and nuts are,

$$m = 95\ nuts\ and\ bolts \times 0.08kg$$

$$m = 7.6kg$$

$$\mathrm{w} = \mathrm{mg} = 7.6\mathrm{kg} \times 9.81\mathrm{m}/s^2 = 74.56$$

Attachment on shaft

Mass attachment on shaft weighs 1kg,

$$1\mathrm{kg} \times 9.81\mathrm{m/s2}$$

$$9.81\mathrm{N}$$

Total Mass of the drum is the sum of all the component masses of every part.

$$m_T = 40.471kg$$

$$\mathrm{w} = \mathrm{mg} = 40.471kg \times 9.81\mathrm{m/s2}$$

$\mathrm{W} = 397.02\mathrm{N}$

Appendix G: Gap Summery of developed turmeric polisher in the past

Table 1. Comparison of previous research with developed turmeric rhizome polisher

Summary of Developed Turmeric Developed Powered Turmeric Polishing Machine				
	1	2	3	4
Author/s	Moghe and Zakiudin	Hoque and Hossain	Shewata Et al	Developed prototype
Material Processed	Turmeric	Turmeric	Turmeric	Turmeric
Tested on Moisture content	----	---	11%	6, 9,11
size		30		
Power source	0.3-kW single-phase induction-type electric motor	0.37-kW single-phase induction-type electric motor	Electric Energy	Diesel/electric Motor (Diesel used for Testing)
Weight processed per batch(kg)	50kg	30kg	10 kg/per	200kg
Capacity(kg/hr)	100kg/hr	63.53kg/hr	30kg/hr	364kg/hr
Drum speed (rpm)	65rpm	27rpm	45, 60, 90 Good at 60 rpm	70,85,95 Good at 85
Operating time per batch	20min	28.5min	15min	15, 20, 25
Labour Requirement	1	1	1	1
Economic Analysis	---	72.27%	Moderation	high
performance	8% (satisfactory)	Satisfactory compared manual and paddle	6-8%	Good
Target	Useful for on farm polishing	Useful for on farm polishing	For small scale processing	Useful for farmer and small scale entrepreneur
Variables		Feed capacity Polishing time	Feed capacity Drum speed	Moisture content Drum speed Operation Time
Easiness	-----	----	---	Can be disassembled and assembled by farmers Easy for transportation

Appendix H: ost summery of material production

Table 1. Cost summery of raw material

No	Material	Unit	Quantity	Unit cost(birr)	Total cost
	50x50mmx6000mm angle iron for frame and engine seat	pcs	3	850.00	2550.00
	2000x1000x3mm mild steel sheet metal drum cover	pcs	1	1200	1200.00
	2000x1000x1mm stainless steel sheet metal (perforated)	pcs	1	7500	7500.00
	1500x30x3mm Stainless steel	pcs	1	1300	1300
	2000x1000x2mm sheet metal for collector	pcs	1	1000	1000.00
	50x5x6000mm flat iron	pcs	3	950	2850.00
	2000x1000mm Expanded wire mesh	pcs	2.5	450	1125.00
	2000x1000mm wire mesh	pcs	2.5	150.00	375.00
	□140x55mm Aluminum pulley	pcs	2	800.00	1600.00
	□100x55mm Aluminum pulley	pcs	1	600	600.00
	□75x55mm Aluminum pulley	pcs	1	600	600.00
	Hollow pipe □20	m	0.5	200	200.00
	V–belt, B-94	pcs	2	120.00	240.00
	V-belt- B-60	pcs	2	120.00	240.00
	Bearing with housing UCP 209	pcs	2	400	800.00
	M20x80 Bolt and nuts	pcs	8	25	150.00
	M8x10 Bolt and nuts	pcs	75	15	1125.00
	M10x40 bolt and nuts	pcs	4	20	100.00
	Speed reducer	pcs	1	3000	3000.00
	5hp engine	pcs	1	8000	8000.00
	Paint	gallon	2	600	600.00
	Antirust	Kg	1	150	150.00
	Cutoff disk	pack	2	280	560.00
	Total				**35, 865.00**

Table 2. Summary of machine and Labor Cost

No.	Equipment/machine	Working time (hr.)	Machine cost/hour		Labor cost		Total Cost
			Cost/hr.	**Sub-total**	**Cost/hr.**	**Subtotal**	
	CNC (for bending)	0.20	100	20	25	15	35.00
	Power hacksaw	31	15	465	25	775	1240.00
	Lathe machine	25	30	750	25	625	1375.00
	Arc welding machine	40	16	650	25	1000	1650.00
	Drilling machine	34	25	850	25	850	1700.00
	Grinding machine	25	20	500	25	625	1125.00
	Shearing machine	18	90	1650	25	450	2100.00
	Rolling machine	9	20	180	25	225	405.00
	Total Cost			**5, 065.00**		**4, 565.00birr**	**9, 630.00**

Table 3. Total machine costs

No.	Variables	Costs
1	Material cost	35, 865.00
2	Machine cost	5, 065.00
3	Labor cost	4, 565.00
4	Wastage of material (2.5%)	896.65
5	Overhead cost 5% (No. 2+3)	481.5
6	Profit Cost 10% (No. 1+2+3+4+5)	2343.66
7	Selling tax (duty free)	0
	Grand Total (Cost of machine production)	**49, 217.22birr**

Table 4. Cost analysis of machine

Cost type	Amount
Machine Cost	49, 217.22birr
Fixed Costs	
Salvage Value	4921.72birr
Depreciation	57.57birr/hr
Interest	5.63birr/hr
Tax	Duty free (reference letter of ME.30/58/9 Dated 21/2/2012 of Ministry of Finance
Insurance	120birr
Housing	876birr
Variable cost	
Maintenance and Repair Cost	1300birr
Fuel Cost	103.49birr/hr. (827.92birr/day)
Labor cost	----
TOTAL COST	57,236.06 birr

Table 5. Income calculation from output of turmeric polisher per day

Machine capacity /hr	**Polishing capacity**
Price of 1kg of polished turmeric	50
Capacity of machine/hr	364
Total price of polished turmeric/in 1hr	18, 000birr
Amount of polished turmeric per day	2912 × 50 birr =145, 600birr/ day

Appendix I: Some practical activities of property measurement

a) 

b) 

Figure 1. Turmeric rhizome a) width measurement b) Bulk density measurement

Annexes