DEVELOPMENT AND PERFORMANCE EVALUATION OF SHEA FRUIT (*Vitellaria paradoxa*) DEPULPING MACHINE

BY

AMINU, Lawal
M.ENG/SIPET/2018/8373

A THESIS SUBMITTED TO THE POSTGRADAUTE SCHOOL, FEDEFAL UNIVERSITY OF TECHNOLOGY MINNA, IN PARTIAL FULFILMENT OF THE REQUIUREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF ENGINEERING (M. ENG) IN AGRICULTURAL AND BIORESOURCES ENGINEERING (FARM POWER AND MACHINERY)

AUGUST, 2023

DECLARATION

I hereby declare that this thesis titled **"Development and Performance Evaluation of Shea fruit depulping Machine"** is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published and unpublished) has been duly acknowledged.

LAWAL, Aminu
(M.ENG/SIPET/2018/8373)
FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA, NIGERIA

____

SIGNATURE / DATE

CERTIFICATION

The Thesis titled: **"Development and Performance Evaluation of Shea Fruit Depulping Machine"** by **LAWAL, Aminu (M. ENG./SIPET/2018/8373)** meets the regulations governing the award of the degree of (M. Eng) of the Federal University of Technology, Minna and it is approved for the contribution of scientific knowledge and literary presentation.

ENGR. PROF. A. GBABO ______________________

SUPERVISOR Signature & Date

ENGR. PROF. S. M. DAUDA ______________________

HEAD OF DEPARTMENT Signature & Date

____

ENGR. PROF.(Mrs.) Z. D. OSUNDE Signature & Date

DEAN OF SIPET

ENGR. PROF. O. K. ABUBAKRE ______________________

DEAN OF POSTGRADUATE SCHOOL Signature & Date

DEDICATION

This thesis is dedicated to Almighty Allah (SWT) and his messenger Muhammad (PBUH), my parent Late Mallam Aminu Muhaammed Gbodoti (May his gentle soul rest in perfect peace) and Hajiya Amina Aminu muhammed Gbodoti, my wife Mallama Hadiza Alhaji Minin, my elder sister Madam Aishatu A. Haruna and my aunty Hajiya Hadiza Aliyu Goro, for their prayers, sacrifices, support and encouragement.

ACKNOWLEDGEMENT

My profound gratitude goes to Almighty Allah (SWT) the creator of the heaven and the earth for his mercy and blessings upon my life and for giving me this privilege to attained this feat in my academic pursuit. My sincere appreciation goes to my supervisor, Engr. Prof. A. Gbabo for his valuable advice, patience, guidance, motivation and fatherly role which translated to the success of this research work. May the Almighty God continue to reward you.

My sincere and heartfelt appreciation goes to my parents, Hajiya Amina Aminu Gbodoti and late Mallam Aminu Muhammed Gbodoti for their prayers. May she live long in good health and never lack as long as she lived Ameen. My sincere appreciation goes to my wife for her patient, certainly the challenges of going through this programme would have been more tasking if my amiable loving wife Hadiza Alhaji Minin had not been with immense support and understanding. I appreciate you' your kindness, thank you.

My special appreciation goes to the head of Agricultural and Bioresources Engineering Department, Engr. Prof. Solomon Musa Dauda and to the departmental postgraduate coordinators Dr. M. Aliyu and to Engr. Prof. A. A. Balami, Prof. Mrs. B.A Adejumo, Engr. Dr. I. S Mohammed, Mr. S.A Shuaib and Engr. Dr, S.E Adebayo, Dr. S.A Muhammed, Engr. P. A. Adeoye. I thank you all for your support.

I will also like to appreciate my friend Mr Usman Muhammed for his immense support and contribution and always available and ready to assist toward the success of this programme. May Almighty Allah continue to bless you and your family Ameen.

ABSTRACT

Shea tree **(***Vitellaria paradoxa***)** is the raw material for shea butter production which plays a significant role in the economy of West African countries. However, the traditional method of processing shea butter involves a laborious and time-consuming depulping process. In this study, shea fruit depulping machine was designed and fabricated to mechanize this process and improve efficiency. The machine comprises the hopper, auger shaft, barrel, pulp outlet, kernel outlet, pulley and support frame. The methodology involved designing for appropriate selection of components for the fabrication of the machine. The effect of machine parameters on the depulping process was investigated at three different moisture levels: 15 %, 20 %, and 25 %. The actual capacity, depulping efficiency, kernel breakage, and pulp loss of the machine were analyzed. Results showed that the actual capacity of the machine increased gradually from 500 to 1000 rpm, with a maximum actual capacity of 22.75 kg/h. Depulping efficiency was highest at a moisture level of 25 % and a machine speed of 500 rpm. The percentage kernel breakage decreased as moisture content increased and as machine speed increased from 500 to 750 rpm, but increased slightly at 1000 rpm. Pulp loss decreased with increasing machine speed, especially at higher moisture levels. At 25 % moisture level, there is a significant decrease in efficiency as the feed rate is increased from 20 kg/min to 40 kg/min. These results show that machine speed and moisture content are important factors to consider when improving the depulping process. Recommendations include operating the machine within the best speed range and the machine speed should be based on the moisture content of the Shea fruits being processed.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Shea tree (*Vitellaria paradoxa*), is a dominant tree species in many agroforestry in Sub-Saharan Africa, belongs to the family of *sapotaceae* which is divided into two subspecies: *paradoxa* and *nilotica* (Tom-Dery *et al.,* 2018). The *paradoxa* is mostly found in the western part and *nilotica* in eastern part of Africa (Odoi *et al.,* 2020). *Nilotica* grows across approximately 4 million square kilometers of sub-Saharan Africa (Akatwetaba *et al.,* 2018)

Under the African culture of unwritten facts, known and told by griots, the Shea tree has been known and used in several different ways for nearly two centuries now, that was the case until in the 18^{th} century when Mungo Park, the British explorer first came upon it in West Africa in 1796 and described the tree as a useful specie (Wilson, 2019). In 1807, Karl Friedrich Von Gaertner (1772 - 1850). A German Botanist, was the first to classify the Shea tree as *Vitellaria*. *paradoxa* (West African subspecies) and *Vitellaria nilotica* (East African subspecies). Comparing different sources (Masters, 2021). Shea trees occur naturally in a 5000 km long and 500 km wide zone stretching from Sudan to Guinea, and can be found in twenty different countries (Shea, 2020).

Processed Shea butter exports in 1998 for the whole of Africa amounted to 1,200 metric tons (MT), worth US$ 571,000. African exports of Shea butter have increased to 3,200MT in year 2000 (Tom-Dery *et al.,* 2019). Major Shea nut importers in recent years were Belgium, Denmark, Japan, the Netherlands, Sweden and the United Kingdom (Wardell *et al*,.2021).

The shea nut tree is the largest tree population size of the economic tree species in Africa. Africa produces about 1.76 million metric tons of raw shea nuts annually (Iddrisu and Mills-Robertson, 2020).

Shea tree is indigenous to Sub-Saharan Africa of which Nigeria is the largest producer of Shea nuts in West Africa (Ugwu-Dike and Nambudiri, 2022). In Nigeria, the abundance of Shea trees exists and thrives almost exclusively in the North, where they mostly grow naturally in the wild. Shea trees usually grow to an average height of about 15 m and girths of about 175 cm. They have profuse branches and a thick waxy and deeply fissured bark that makes it fire-resistant (Nair *et al.,* 2021).

However, local inhabitants of Shea growing areas say that no one owns the Shea tree, since it germinates and grows on its own. The Shea tree becomes fire-resistant after it passes the germination stage of a period of three to five years. Once it survives the first five years of its early stages of germination and growth, it grows slowly and takes about fifteen years to reach maturity and can live for up to about three hundred years and bearing fruit for over two hundred years (Amoako and Gambiza, 2021).

The fruit of the Shea tree ripens during the annual hunger season when food supplies are at their lowest ebb and agricultural labour requirements are at their peak. The fruit, which is green in colour, has a fleshy edible pulp, it is rich in vitamins and minerals and not lacking in protein. The iron and calcium content compared favorably with raspberries: 1.93 mg/100 g as against 0.92 mg/100 g for iron, and 36.4 mg/100 g as against 26 mg/100 g for calcium (Ejotre *et al.,* 2022). The fruit pulp, being a valuable food source, is also taken for its slightly laxative properties. Although not wide spread minor uses include cosmetics and pharmaceuticals. The fruit is also an important source of food for many organisms, including birds and bats (Ejotre *et al.*, 2022).

The shea fruit (Plate I) is a berry which is hard when raw and soft when ripe but generally green from outside when raw or ripe. The shea fruit is a naturally profiled layer of four which consists of a thin epicarp and a soft mesocarp enclosing a single seed, sometimes two or more (Aneni *et al.,* 2020).

Plate I: Shea fruit

(Source: Abdul-Mumeen *et al.*,2019)

The thin epicarp and the soft mesocarp constitute the pulp which is very sweet and highly nutritious when ripe. The pulp (Plate II) is widely consumed in areas where the shea tree species occurs and it is a rich source of sugars, proteins, calcium, ascorbic acid, and iron (Falola *et al.,* 2022). The pulp surrounds a relatively large oily-rich oval, brown seed, referred to as shea nut from which shea butter is extracted (Abdul-Mumeen, *et al.,* 2019). The enclosed nut has a shiny, smooth surface and comprises about 50% of the fresh weight of the fruit (Iddrisu and Mills-Robertson, 2020).

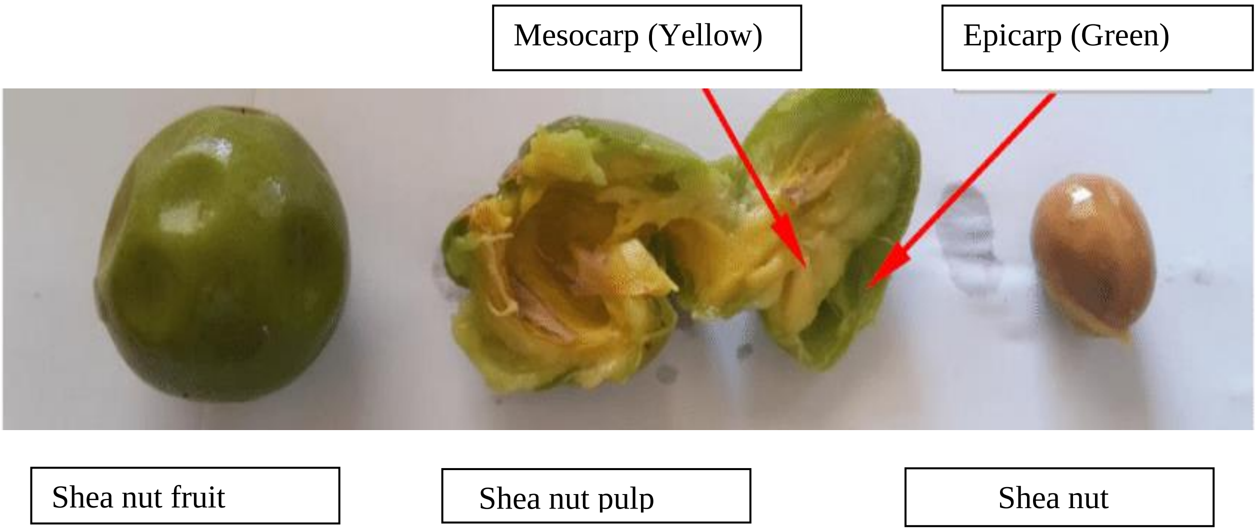


Plate II: Shea nut fruit, pulp and the nut

(Source: Abdul-Mumeen *et al.*,2019)

The mature kernel contains 61% fat which when extracted is edible, a crucial nutritional resource for millions of Nigerian rural households and can serve as medicinal. The oil extracted from the kernel (45- 60 %) is important in the U.K as cocoa butter substitute in chocolate manufacture. Greater quality assurance of the Shea butter throughout the supply chain is a pre-requisite if the Shea tree is to reach its full nutritional resource for rural and urban households across the nation and for future generations. The pulp constitutes about 60- 80% of fruit weight, and during the processing of the shea nut for shea butter extraction, the pulp is first removed by a process known as depulping through unguided fermentation in mass quantities (Iddrisu and Mills-Robertson, 2020).

1.2 Statement of the Research Problem

The production of shea butter is an important source of income for many communities in Africa, particularly for women who are involved in the processing of the shea fruits. However, the depulping process for shea fruits is often done manually, which is time-consuming (Oduro *et al.*, 2021) and labor-intensive making it difficult to process large quantities of shea fruit (Rotta *et al.*, 2021), and can lead to low yields and poor quality shea butter (Abdul-Mumeen *et al.*, 2019). The manual depulping of shea fruit yield 6.25 kg/h capacity (Oduro *et al.*, 2021), this value is very low compare to the increasing demand to cater for 600,000 MT of shea fruit annually, the low depulping rate leads to it negative economic impacts (Gemechu, 2020). Therefore, there is a need for a more efficient and sustainable depulping machine for shea fruits that can improve the productivity of shea butter production. The purpose of this research work is to develop a shea fruits depulping machine that addresses these challenges and supports sustainable economic development in local communities.

1.3 Aim and Objectives

The aim of this research study was to development and performance evaluate of Shea fruit depulping machine.

The objectives of the study are to:

1. Design a shea fruit depulping machine.
2. Fabricate shea fruit depulping machine.
3. Test and evaluate the performance of Shea fruit depulping machine.

1.4 Justification for the Study

The developed depulping machine for shea fruits will improve the efficiency and productivity of shea butter production, while also supporting the economic development of local communities. A depulping machine can help reduce the time and labor required for depulping, increase yields and quality of shea butter, and minimize waste. In addition to analyzing the efficiency of the shea fruit depulping machine, this research also investigated the traditional, local methods of depulping shea fruit.

This research study is also aligned with the United Nations Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth). By supporting sustainable economic development through the development of a depulping machine for shea fruits, this research project can contribute to poverty reduction and job creation in local communities. Consequently, the development of a shea fruits depulping machine is an important and timely research project that can have significant social, economic, and environmental impacts.

1.5 Scope of the Study

The scope of this research is to develop and carry out performance evaluation of shea fruit depulping machine. the depulping machine fabricated will be evaluated at speed of between 500 to 100 rpm, feed rate of 20 to 60 kg/h and shea fruits moisture level of 15 to 25 %.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Depulping Process

The depulping process is a critical step in the production of many agricultural products, including coffee, cocoa, and fruits like Shea. It involves removing the outer pulp or husk from the seed or fruit to access the valuable inner product. In the case of shea fruit, the depulping process is necessary to access the Shea nut, which contains the butter used in many cosmetic and food products. Traditional depulping methods involve using hand tools or mortar and pestle to crush the fruits and remove the pulp, which is time-consuming and labor-intensive (Gemechu, 2020).

However, modern depulping machines have made the process more efficient and scalable. These machines can remove the pulp and husk from large quantities of shea fruit quickly and with minimal labor input (Gemechu, 2020).

Research into the depulping process has focused on optimizing the efficiency and quality of the depulping process, reducing waste, and improving the overall yield of the product. Studies have looked at factors such as the effect of moisture content, pulping temperature, and equipment design on the efficiency of the depulping process (Rotta *et al.,* 2021).

2.2 Traditional, Local methods of Depulping Shea Fruit

These methods include manual depulping, pounding, and boiling.

2.2.1 Manual depulping

Manual depulping involves using a sharp knife or machete to cut away the outer pulp layer of the fruit. This process is labor-intensive and time-consuming, making it difficult to process large quantities of fruit. The resulting pulp is typically of lower quality and may contain more impurities than pulp produced by machine depulping.

2.2.2 Pounding

Pounding involves using a large wooden mortar and pestle to break up the fruit and separate the pulp from the kernel. This method is also labor-intensive and requires significant physical exertion. While it can produce higher-quality pulp than manual depulping, it is still difficult to scale up for large-scale processing.

2.2.3 Boiling

Boiling is another traditional method of depulping, which involves placing the shea fruit in a pot of boiling water and allowing it to cook for several hours. The outer pulp layer is then removed by hand. While this method can produce high-quality pulp, it is time-consuming and requires a significant amount of fuel to maintain the boiling water.

However, these traditional depulping methods are generally less efficient and more labor-intensive than depulping machine. They may still be used in remote areas where access to depulping machines is limited, but for large-scale commercial processing, machine depulping is the most practical and efficient option (Jasaw *et al.*, 2018).

Historically, for more than 1000 years, *Vitellaria* has been a major component of West African agroforestry systems, being highly valued primarily for the oil obtained from the dried kernels (Dagar *et al.*, 2020).

Through the generations farmers have selectively chosen which trees to cut down and which to leave standing on their valuable agricultural land. Due to its numerous local uses and sources of income as a cash crop, this process of selection has led to Vitellaria becoming the dominant tree in most parkland systems in the West African savannah landscape (Amoako and Gambiza, 2021).

In 1977, *Vitellaria* was included on the list of tree species constituting African forest genetic resource priorities for situ conservation at the fourth session of the 294 Food and

Agriculture Organization (FAO) Panel of experts on Forest Genetic Resources. In the 1980s, this huge amount of interest and attention led to calls for Complement receptor of immunoglobulin superfamily (CRIG) to increase botanical and genetic exploration with research focusing on diversity, management and propagation of *Vitellaria* (Cheng *et al.*, 2019).

Almost 30 years have passed since these calls were first made and only limited amounts of information with regards to optimum growing conditions and improving the marketing of Shea products has been gained (Tom-Dery *et al.*, 2018).

The shea tree grows in the Sahel-Savannah belt, which (with the addition of South Sudan) includes twenty-one sub-Saharan Africa countries and extends from Senegal, in the West, to Ethiopia, in the East and has long had a significant positive impact on the human populations living in these areas, providing a staple edible oil, fuel wood, building material, soil protection and honey from the bee pollinators (Hale *et al.*, 2021).

The shea tree is considered by some to be a semi-domesticated tree crop having been through centuries of cyclical unconscious on-farm selection (Abidemi and Hamilton, 2021). It is both endemic to the Sahel-Savannah region of sub-Saharan Africa and it is a traditionally protected indigenous tree in many of the areas where it grows, People, cattle, bats, birds and other animals disseminate the seeds (Jasaw *et al.*, 2018).

However, the trees are not traditionally planted in a domesticated manner but rather the decision to keep or to cut naturally regenerating saplings as a component of an agroforestry system, means the trees are selectively managed, with the result that semi-domestication is potentially occurring through the process that describes as automatic or unconscious selection.

Therefore, they mostly grow naturally in the wild, the long period taken to reach maturity has discouraged its planting in an organized plantation and produces its first fruits (which resembles large plums) when it is about 20 years old and reaches its full production when the tree is at about 45 years old and continue to produce nuts for up to two hundred (200) years (Adesope *et al.*, 2022).

Shea trees usually grow to an average height of about 15 m and girths of about 175 cm. They have profuse branches and a thick waxy and deeply fissured bark that makes it fire-resistant and it has been utilized in West Africa for almost 3000 years and studies has shown that the morphological traits of shea stands in this region suggest that this tree was first semi-domesticated on Mossi plain in Burkina Faso (Asare *et al.,* 2019).

In Nigeria, the abundance of Shea trees exists in and thrives almost exclusively in the North, where they mostly grow naturally in the wild and fund growing abundantly in Niger, Nassarawa, Kebbi, Kwara, Kogi, Oyo, Ondo, Kaduna, Adamawa, Taraba, Borno and Sokoto States (Animasaun *et al.,* 2019).

Niger State ranks first in terms of density and distribution of the tree and Nigeria is the largest producer of shea nuts in West Africa and the shea trees have potentials to contribute significantly to the economic and industrial development of Nigeria and by extension improving the quality of life of the people (Yeboah *et al.,* 2020).

This wild tree species (Plate III) is protected and maintained on farmed fields in most of the parklands of Sudanian and Sudano-Guinean zones in West Africa and plays a significant socio-economic role. Shea trees bear fruits whose nuts are cherished locally and internationally for their high oil content and it is the most important source of oil for the people in the shea belt (Baiyeri *et al.,* 2019).

The effect of human management on both the population structure of this important trees and its potential role in the semi-domestication of this species have been described where a range of selection mechanisms are proposed to have influenced a variety of characters including shea nut variation and yield (Hale *et al.*, 2021).

(a) **(b)**

Plate III: Shea Tree

(Source**:** Abdul-Mumeen *et al.*, 2019)

However, due to the economic importance of the shea tree has lead research scientists to undertake investigations into its silviculture and ecology but little is known of the pattern of genetic variation within and among natural populations (Aleza *et al.*, 2018).

A good understanding of the variation within a species is necessary for its domestication, conservation and sustainable management. Therefore, there are different ways to assess genetic diversity and genetic structure within a species. Molecular markers now play an important role in the comprehension of genetic dynamics at different scales of time and space (Houndonougbo *et al.*, 2020).

The first attempt to describe the genetic variation of this species was undertaken at a national level in Ghana using iso-enzymes. The first studies using DNA were done on leaf samples of the shea tree across its natural range in order to understand the influence of last glaciation period (20,000–15,000 BP) on the dynamics of the species diversity using randomly amplified polymorphic DNA and chloroplastic microsatellites. These molecular analyses, however, do not provide information for a comprehensive pattern of the variation of quantitative traits important for the management of genetic resources, particularly in countries where this tree species is of primary economic importance in the agroforestry parklands (Hale *et al.*, 2021).

2.3 Economic Important of Shea Tree

The shea fruit is a valuable crop with significant economic importance, particularly for many African countries. Research on shea fruit can provide numerous benefits and contribute to the development of various sectors of the economy and research on shea fruit can improve agricultural productivity and enhance the income of farmers. With improved processing methods and increased yield and quality, farmers can benefit from increased productivity and profitability (Kamga, 2023).

The food industry can benefit from shea fruit research, with the development of new food products and the improvement of existing products. Shea fruit is a key ingredient in various food products such as chocolates, ice creams, and confectioneries, and better processing techniques can enhance the quality and taste of these products (Seghieri, 2019).

The cosmetics industry can benefit from shea fruit research by developing new and improved products based on the moisturizing and healing properties of shea butter, which is extracted from the shea fruit. This can lead to increased demand and create new market opportunities for the cosmetics industry. It can contribute to international trade by improving the quality and standard of shea products and can also increase the export potential and foreign exchange earnings for countries that produce shea fruit (Seghieri, 2019).

The economic importance of the shea tree lies in its high demand for its butter, both locally and internationally, mainly as a cocoa butter substitute in the production of chocolate. With increasing international interest in shea butter as a cocoa butter equivalent in the confectionery, pharmaceutical, and cosmetic industries, the shea tree has become a crucial source of income for many communities. Its role in food production, foreign exchange earnings raw materials for industries, income and employment generation to millions of Africans most especially women and young people makes it a crucial asset for National Economic Development (Wardell *et al.,* 2021).

It is obvious that apart from the nutritional and medicinal properties of Shea nut tree, the evidences on its economic and environmental importance to the economy of the Africa are enormous. With adequate exploitation, the tree has the potentials to make significant contribution to the country's Gross Domestic Product (GDP). The current shea nut export are rather unreliable, but a conservative estimate suggests that it was one of the main export commodities in some African countries such as Burkina Faso which worth USD 21.5 and 14.7 million in revenue in 2008 and 2009, respectively (Pitigala and Lopez, 2021).

The tree serves as source of income to many people, especially women in the North Central States of Nigeria, but the level of income received is generally low when compared with the potentials. This has to do with the handling and processing methods adopted which result in low quality of fruits and butter which fetch low prices and this reduces access to international markets. This situation is worsened by lack of awareness of the collectors and processors of superior handling and processing methods and equipment. Even in cases where they are aware, the cost of such equipment is generally beyond what they can afford as individual operators. Secondly, most of the collectors and operators are in small, scattered and remote areas which make access to markets difficult resulting in low prices. Thirdly, they lack bargaining power as they operate mostly as individuals. This frequently places them at the mercy of middlemen who usually go into the rural areas to purchase the nuts and butter. The collectors and processors who are mostly women therefore do not reap the expected benefits and recognition for their labour. However, to develop and derive more rewarding benefits from the shea tree, the socioeconomic analysis of its benefits becomes pertinent. This will be vital to policy makers as it will help them appreciate how different socioeconomic units of a population will affect existing policies and also help develop more user-friendly policies (Essouman *et al.*, 2021).

However, over the past 10 years, demand for shea products has grown in both the European Union (EU) and the United States (US) and the global demand for shea butter is worth about $10 billion and is projected to be worth about $30 billion by the year 2020 (Kelly *et al.*, 2019).

Koloche *et al.*, (2023) reported that Shea nut exportation increased and was directed to Asian and European countries. The total collectible production of Shea butter in 2015 was 600,000 tons valued at $10.6 billion in 2016 (Kelly *et al.*, 2019).

According to Daudu *et al.*, (2019), 5% of exported Shea nut go into cosmetics industries and the rest (95%) goes to food industry principally chocolate manufacturing. Statistics reported by Market Research Future; Kelly *et al*, (2019) indicated that almost half of the Shea production never reaches the international market and is consumed locally and that Nigeria contributes more than 50 % of the global shea exports followed by Mali, Burkina

Faso, Ghana, Côte d'Ivoire, Benin, and Togo. While the interest for shea products is growing, shea tree populations and shea fruit production are facing several constraints. Declining tree densities in parklands in several agricultural areas of the Sahel has been highlighted by many studies. The combination of drought and increasing population pressure (thereby resulting shortened fallows) and also threat by a plant parasite of the genus *Tapinanthus* are decreasing the shea populations (Kelly *et al.*, 2019).

In recent years the tree has gained importance as an economic tree because of the heavy demand for its butter, both locally and internationally, and the need to find substitutes for cocoa butter. Shea butter is a useful cocoa butter substitute because it has a similar melting point (32–45°C) and high amounts of di-stearin (30 %) and some stero - palmitine (6.5 %) which makes it blend with cocoa butter without altering flow properties. The high proportion of unsaponifiable matter, consisting of 60–70% triterpene alcohols, gives shea butter creams good penetrative properties that are particularly useful in cosmetics (Daudu *et al.*, 2019).

Therefore, in recognition of the need to find substitutes for the rather expensive cocoa products, and to maximize economic exploitation of the vast shea resource in Nigeria, the federal government of Nigeria included shea tree as one of the mandate crop of economic importance to the Nigerian Institute for Oil Palm Research (NIFOR). This led to the establishment of NIFOR shea nut tree research. The sole responsibility of this sub-station is to research into the economy, ecology and biology of the shea tree and with the aim of improving its yield. The research sub-station, apart from providing job opportunities for researchers and others, it will also provide avenues for increased production of shea nut yields if extended to the end users. And consequently, shea nut output, for both export and local consumption, will increase tremendously in the next few years (Koloche *et al.*, 2023).

The Nigerian Agricultural industries have the potentials to contribute significantly to the economic and industrial development of the nation, especially with the wide range of industrial application of most of the nation's agro-produce like shea nut. Nigeria is fairly blessed with shea trees which could be harnessed for industrial development through which the quality of life of the people will be improved. The shea tree occupies a pre-eminent position in the Nigerian economy in providing employment to a large number of people on the shea tree belt if special consideration is given to its organized planting. However, a quite sizeable portion of unemployed population will find ready jobs if the opportunities provided by the numerous applications of shea nuts were fully tapped and the planting, harvesting and processing of Shea nut in to fat and oil or (butter) and the kernels into shea Nut Cake (SNC) will not only provide business opportunities to millions of Nigerians mostly in the shea tree belt, it will also offers a wide range of investment opportunities that are economically attractive to the people at home and abroad and therefore play a major role of shea in food production, foreign exchange earnings, raw materials for industries, income and employment generation to millions of Nigerians including women and young people makes it a very crucial asset for National Economic Development (Wajim, 2020).

The shea tree also comprises a unique resource for rebuilding the lives and livelihoods of rural farmers, this resource were already in use by mostly women and children to generate substantial income to support their domestic needs which in the medium- term, alleviates poverty amongst the rural women and in the long-term provides continuous employment opportunities for both rural women and young people, and not only that the economic environmental and other benefits of shea tree to the Nation is undoubtedly clear in providing revenues for increased income from both export and local consumption. This will also open new frontiers for the country in the world export market for shea products as a substitute to palms of economic value. Local farmers on the other hand, who have become serious about production and protection of shea resources, will generate income to sustain their families and improve the quality of their lives (Choungo *et al.,* 2021).

2.4 Uses of Shea Tree and Shea Nut

The shea tree produces fruit which has multiple uses on a local level, is highly nutritious and is also a valuable commodity on local, national and international markets, making it the ideal candidate to research and invest into. Today the shea tree produces the second most important oil crop in Africa after palm oil but as it grows in areas unsuitable for palm growth, it takes on primary importance in West Africa (Dimobe *et al.,* 2020).

Shea nut products have both domestic and international applications, with Europe being the primary importer. In Africa, specifically West Africa, Nigeria holds the distinction of being the largest producer of shea nut, contributing approximately 58 % of the total production in 2008. To ensure a promising future for shea products in any country, it is crucial to focus on various aspects such as research and development, enhancing shea productivity and product quality, technology transfer, diversification, and improving the infrastructure related to the sector (Wardell *et al.,* 2021). Shea trees are therefore economically important to the local economies and lifestyles of many African traditional communities. The shea tree produces fruit which has multiple uses making it a crop of research and investment interest today. Shea tree currently produces the second most important oil crop in Africa after palm oil especially as it grows in areas unsuitable for palm and in regions where annual precipitation is less than 1000 mm of rainfall. However, it losses popularity in urban areas within these regions due to the pungent odour it emits, when it becomes rancid. Its healing and soothing properties are thought to be attributable to a substance called "allantoin" which is known to stimulate the growth of healthy tissue in ulcerous wounds (Asare *et al.,* 2019).

Baiyeri *et al.* (2019) Stated the benefits derived from the shea butter tree as follows – the pulp of the fruit is edible while the bark and root are used in traditional medicine and the products are widely used for domestic purpose for eating, cooking, lightening, skin moisturizer and commercially as ingredients in cosmetic, pharmaceutical and edible products.

Locally, it is used in childhood ointments for minor scrapes and cuts, and the shell of the nuts can be used to repel mosquitoes. Above all, the seed, when crushed, yields a vegetable oil that can be used in cooking, soap making, skin and hair care. This makes it a valuable trade commodity. Collecting the nuts and making butter have traditionally been women's work.

The pulp of ripen fruits is very nutritious and provides a key dietary supplement to local people, especially at the end of the dry season when the stocks of staple grains are low. The shea fruit pulp is eaten as a food supplement, especially during the dry season when the fruits mature and ripen. In some African countries such as Burkina Faso, shea fruit pulp is locally processed into fruit jam (Choungo *et al.*, 2021).

Shea trees are also utilized for medicinal and cultural purposes, such as in the treatment of wounds, making of funeral beds, pregnancies, births and weddings. There are reports of the use of shea oil in war rituals by some traditional communities in Uganda and butter is used in many African kitchens but also in pharmacology, cosmetics, traditional medicine and as Chocolate Butter Equivalent (CBE) in chocolate industry (Hale *et al.*, 2021).

Shea is considered a women's crop and the extraction, processing, and commercialization of shea fruits, kernels, and butter are some of the few activities that are almost entirely under the control of women. Despite the historical centrality of rural women in shea nut collection and processing, female agriculturalists have been repeatedly ignored in studies pertaining to shea agroforestry (Koloche *et al.,* 2022).

The shea butter processing in Nigeria is mostly done traditionally by women in the rural area; the procedure is quite tedious and time consuming, from collection of the shea fruits to the production of the final product and a variety of methods are used traditionally to remove the husks and these include trampling, pounding using a mortar and pestle, and cracking between two stones. the procedure is quite tedious and time consuming, from collection of the Shea fruits to the production of the final product (Oduro *et al.,* 2021).

In removing the oil from the kernels, it is estimated that the production of 1 kg of shea butter takes one person 20-30 hours and that 8.5-10.0 kg of wood fuel is needed to produce it (Miazek *et al.,* 2022). This means that energy input is quite high. No estimates exist of the overall balance between cost of input energy and the economic profit from the sale of shea butter. The traditional oil extraction technique of shea butter is time consuming, physically exhausting and requires large quantities of fuel wood and water; resources that are often scarce in the regions where the butter is produced. In general, it is also inefficient in terms of the amount of fat extracted, however, these could be improved in the modern way, and without doubt, the shea nut output, for both export and local consumption, will increase tremendously (Abdul-Mumeen *et al.,* 2019). Therefore, it will be appropriate that the national economic searchlight for national development focus on developing shea nut tree especially in the aspect of processing and marketing of its kernels so that the current over dependence on crude oil as the main source of the country's revenue could tilt a bit in favor of agricultural produce as it were before the discovery of crude oil. Shea butter is a good sun screening agent. Sun-screening agents act by absorbing or reflecting some of the ultraviolet (UV) radiation from the sun and prevents it from reaching the skin. This helps to protect the skin from sunburn, preventing erythema and also reducing further risk of skin cancer induced by the sun's rays (Balkrishna *et al.,* 2023).

According Miazek *et al.* (2022) to photo carcinogenesis is mainly caused by ultraviolet B (UVB) radiation between the ranges of 290 and 320 nm. İt interacts with the DNA directly thereby forming cyclobutane pyrimidine. Cinnamate esters of triterpene alcohol are the main constituent of shea butter's unsaponifiable fraction, these esters have been reported to have strong ability to absorb UV radiation of the wavelength range 250-300 nm. This therefore makes the addition of shea butter's unsaponifiable components into sunscreens increase the absorption of UVB radiation by providing synergistic sun-protection.

During the cold season and summer when the weather is extreme, shea butter is considered as the best skin care during the period because it provides the extra moisture, nutrients and protection needed by the skin. It is also used in the pharmaceutical and cosmetic industries as an important raw material and or a precursor for the manufacture of soaps, candles, and cosmetics. Shea butter is used as a sedative or anodyne for the treatment of sprains, dislocations and the relief of minor aches and pains. The main constraints encountered with nut production are the remarkable decrease of the production and its huge fluctuation from year to year. Many attempts were made to explain factors underlying this fluctuation. Variations of shea fruit production are believed to follow cycles of two, three or more years but a relationship with climatic parameters has not been clearly identified (Kelly *et al.,* 2019).

Fluctuation may also result from differential success in pollination and thus, authors have hypothesized many combined biotic and abiotic factors underlying the annual variation of shea trees' fruit production but this process remains still not fully understood (Kelly *et* *al.*, 2019). Choungo *et al.* (2021) stated that, where estimates are made for either parameter, circumstantial details concerning the population under consideration are frequently lacking. Nevertheless, a better knowledge of nut production and shea tree productivity are essential for management and domestication strategies. In addition, although shea tree conservation is essential for continued shea butter exploitation, the variables causing male and female cultivators to maintain, or eliminate, shea trees in their fields have not been systematically studied.

As Elias (2016) explained, more generally, "some researchers have attempted to develop conceptual frameworks to assess which factors motivate indigenous or peasant farmers to conserve biodiversity, but to date these have neglected to consider gender relations as potentially significant.

2.4.1 Medicinal properties of shea tree

Mankind has always depended on plants for food, clothing, shelter and medicine, medicine from plant sources have been used to cure, treat and prevent sicknesses and injuries to people. For centuries the shea tree and its products has been used for food and medicine in Sub-Saharan Africa. Available records show that, as far back as 1728, shea butter was considered a highly prized medicinal substance in many parts of Africa (Maanikuu and Peker, 2017).

Shea butter stands out because of its high fraction (about 8 %) of content with medicinal properties. It contains essential fatty acids, and helps to protect and revitalize damaged skin and hair. It is known to be naturally rich in vitamins A, E, and F, and other vitamins and minerals. Vitamins A and E help to smooth, hydrate, and balance the skin and they also provide skin collagen acting as anti-agents for wrinkles and other signs of ageing (Han *et al.*, 2022).

Shea butter is a perfect dry skin moisturizer and is also an effective product in a form of cream for revitalizing dull or dry skin on the body or scalp. It is a good agent for skin renewal, increases circulation, and accelerates wound healing and for the treatment of many other ill conditions. Similarly, shea butter is used as protection against sunburns hence it is found in most post sun-exposure products. In some parts of Africa, it is used as pre-warm bath cream for babies to promote smooth supple skin (Han *et al.*, 2022).

i. Healing qualities: Shea butter has great healing properties and is often used as a base in medicinal ointments due to its anti-inflammatory properties. Due the presence of several fatty acids and plant sterols such oleic, palmitic, stearic and linoleic acids shea butter is known to possess some healing properties. These oil-soluble components do not undergo saponification or convert into soap on coming in contact with alkali. Shea butter is more non saponifiable than other nut oils and fats, thus imparting it a great healing potential for the skin. Raw, unrefined shea butter is effective in curing skin rashes, skin peeling after tanning, scars, stretch marks, frost bites, burns, athletes foot, insect bites and stings, arthritis, and muscle fatigue. Also due to its high content of vitamin A, it is effective in promoting healing and disinfection, and soothes skin allergies like poison ivy and insect bites. Shea butter contains Vitamin F which has the ability to act as a rejuvenator for soothing and healing rough and chapped skin (Choungo *et al.,* 2021)

ii. Anti-aging Properties: Shea butter has been considered one of the best anti-ageing and moisturising agents for the skin. It is that shea butter has UV anti-erythemic activity and it property helps to soften the skin and stimulates cell regeneration hence reduce the aging process. There is also an indication that shea butter prevents photo-aging and known to boost collagen production (Afandi and Sahudin, 2022).

The major structural proteins that makes the skin tough and provides plumpness and α-amylin and lupeol are collagen and elastin. These triterpenes are found in the unsaponifiable fraction of shea butter. The inactivation of proteases such as metalloprotease and serine protease are reported to be affected by these triterpenes. The unsaponifiable components are also reported to contribute to anti-aging and collagen-boosting activities (Abdel-Razek, *et al.*, 2023).

It is used as a rub to relieve rheumatic and joint pains and is applied to activate healing in wounds and in cases of dislocation, swelling and bruising. It is widely used to treat skin problems such as dryness, sunburn, burns, ulcers and dermatitis and to massage pregnant women and small children. It is also used to treat horses internally and externally for girth galls and other sores. The healing properties of Shea butter are believed to be partly attributable to the presence of allantois, a substance known to stimulate the growth of healthy tissue in ulcerous wounds (Choungo *et al.,* 2021).

iii. Effect on Cholesterol Metabolism: It is reported that shea butter can lower cholesterol levels when used. They also observed that the usage of shea butter leads to a reduction in low density lipoprotein (LDL) and total cholesterol, the high stearic acid content in shea butter is reported to have antihypercholesterolemic effects (Chen *et al.,* 2019).

İn a different study by Sinaga *et al.,* (2021) on rats they reported that when rats were fed with Shea butter there observed a significant reduction in High density lipoprotein (HDL), Total Cholesterol and Low density lipoprotein (LDL). The presence of saponins in shea butter was said to be responsible for the anti-hypercholesterolemic effect and Saponin as present in the unsaponifiable fraction of shea butter, is said to have the ability to lower the serum cholesterol level by forming mixed micelles with cholesterol and bile acids in the intestine and the process inhibits the absorption of cholesterol and thereby increasing its excretion.

iv. Effect on Protein Metabolism: when shea butter is administered, it is reported to lead to a decline in the overall protein concentrations of the hepatic and renal tissues and also in the serum. This decline has been attributed to the presence of saponin, Saponin has been reported to cause a reduction in protein digestibility by the forming sparingly digestible saponin-protein complexes in the intestine (Alao *et al.*, 2021).

Mixed with tobacco, the roots are used as a poison by the Jukun of northern Nigeria. Infusions of the bark have shown to have selective anti-microbial properties, as being effective against Sarcina lutha and Staphylococcus mureas but not mycobacterium phlei as well as for diarrhea or dysentery (Ali *et al.*, 2022).

Refuse water from production of Shea butter is used as a termite repellent. In Burkina Faso, Shea butter is used to protect against insect (Callosobruchus maculatus) damage to cowpeas. Research has shown that after treatment with shea butter a reduction occurs in the life span and fertility of the insects and hence the infestation rate. Shea butter, however, is not as effective as cottonseed or groundnut oil (Choungo *et al.*, 2021).

The benefit and function of vitamin E in human being is not entirely clear, it has been described as effective in a number of conditions or circumstances. These benefits include being antiaging, an anti-free radical agent and exerting a positive effect on increasing the microcirculation. The shea tree can be used to combat the problem of desertification. Men, women, and children eat and appreciate the pulp and fresh fruits are also sold in local markets (Choungo *et al.*, 2021).

However, despite the economic and environmental benefits of the tree, efforts have not been made to propagate its production by the farmers as the shea tree still grows in the wild state. Another worrisome development is the people's habit of destroying the trees for charcoal production which may eventually lead to environmental degradation, deforestation and loss of vegetative cover and resulting to water and soil erosion. Non-replacement or domestication of the shea trees may lead to its extinction in the nearest future. Traditionally, shea butter is rubbed on pregnant women during childbirth, new born babies and adolescents because of its soothing properties (Daae *et al.*, 2022).

2.4.2 Traditional uses of the shea tree

The shea tree has immense economic and social value to the communities in which it grows. All parts of the tree have one or more uses. The leaves of the shea tree contain saponin which makes it lather in water and hence is used in washing. In northern Ghana the leaves are used in medicine for the treatment of stomach ache especially in children and leaves are also used in a mixture with other leaves in a traditional mixture to produce a vapor which is used to bath persons for the treatment of fevers and headaches. The leaves when soaked in water turns to a soapy and frothy liquid which is used to bath the head of persons suffering from fever. İn cases of eye problems a leaf decoction can be used as treatment (Afful *et al.*, 2022).

In the production of the dawadawa, the most common and widely used local spice in northern Ghana, the leaves of the shea tree are used as a preservative. The pulp of the shea fruit is a rich source of some micro nutrients including ascorbic acid (196.1 mg/100 g), in comparison with an orange, which contains only 50 mg/100 g. Shea nuts contain 1.93 mg/100 g of iron and 36.4 mg/100 g of calcium. The B group vitamins is also a constituent of the shea fruit pulp. The pulp also contains a high sugar content made up of glucose, fructose and sucrose equally distributed and constitute up about 3 to 6 percent. Even the flowers of the shea nut tree are consumed by some ethnic groups that make them into edible fritters (Sodimu *et al.*, 2022).

The roots of the shea tree are used by locals in Northern Nigeria as chewing sticks for cleaning the teeth and the roots are also combined in mixture with the bark in traditional medicine for the treatment of jaundice, diarrhea and stomach pain. The root bark is boiled and pounded and used for treating chronic sores in horses. The roots are mixed with tobacco to produce poison among the Jukun ethnic tribe in Northern Nigeria. The bark of the shea tree is boiled and taken as a beverage. This beverage is claimed to be able cure diabetes in some communities in Ghana.

In some West African countries including Senegal and Guinea, infusions of the bark which are crushed together with the bark of Ceiba pentandra and salted are used to treat worm infestations in livestock. In Guinea Bissau a range of sicknesses ranging from diarrhea and dysentery to gastric problems and even leprosy have been treated with bark infusions. In the Ivory Coast, child delivery is eased by the use of a bark decoction in baths during labour. This decoction is also believed to boost the flow of milk and hence is drunk by lactating mothers. A bark infusion is used as an eye wash against venom of the spitting cobra because it has the capacity to neutralize the venom. It is used as foot bath to extract jiggers in Ghana (Vandebroek *et al.*, 2020).

2.5 Description of Shea Fruit

Shea fruits grow on the African Shea tree (Plate IV) which can live for up to 300 years and take 20 to 30 years to reach maturity and to begin producing fruit, once they do, they can produce fruit for the next 200 years and usually grow to an average height of about 15 m and girths of about 175 cm. They have profuse branches and a thick waxy and deeply fissured bark that makes it fire-resistant. The shea fruit is a green oval shaped fruit which ranges in size from 2cm to 5cm in diameter and the fruit is made up of a green epicarp, a fleshy pulp or mesocarp and a relatively hard shell or endocarp which encloses a shea kernel or embryo and the fleshy pulp is sweet and is eaten as food and the pulp is also used to make jam (Naangmenyele *et al.,* 2023).

The fruits contain a relatively large and oily kernel, or nut, used to make Shea butter. The fruit pulp, made up of the epicarp and mesocarp, constitutes up to 50–80% of total fruit weight and could be fed to livestock. The fruit is widely consumed among African peoples among whom the species occurs, and it is even sold in local markets and the fruit are typically gathered and processed by locals and provide an important source of income for the people of the African sub-Saharan savanna and are known locally as “green gold (Abdul-Mumeen *et al.,* 2019).

Shea fruit ripen at a very critical time of the year – the early part of the rainy season when labour intensive farming operations need to be carried out. The fruits resemble green plums and have round and elongated or torpedo-like shapes and have a smooth green skin that may have slight vertical ribbing. Beneath the skin is a thin layer of yellowish-green pulp that softens as the fruits ripen and in the center, there is a large, smooth brown, nut with a rough spot the size of a thumbprint and pulp is mildly sweet with the texture of a ripe pear and the fruit offers a mild and nutty flavor. However, the fruit consists of a thin, tart, nutritious pulp that surrounds a relatively large, oil-rich seed from which shea butter is extracted. It's a deciduous tree usually 7–15 m tall, but has reached 25m and a trunk diameter of 2 m (Sanchi *et al.,* 2022).

a b

Plate IV: (a) Shea fruit stock (b) Shea fruit

(Source: Abdul *et al.*,2019)

2.6 Nutritional Benefits of Shea Fruit

Fruits are one of the most important foods to mankind and its usefulness can be traced back to the early man ages when it serves as the foremost source of food for man during which he engaged in hunting and gathering so as to survive from age to age. These fruits contain vitamins, enzymes, minerals; natural sugars and cellulose (Kolo *et al.*, 2022).

The nutrients contained in fruit can be absorbed within minutes and it has low calories and so fresh fruits juice should be included in any weight lose plan to provide abundant vitamin and mineral nourishment with little calories. It has been estimated that over 70 % of cancer cases is attributed to diet. Several research studies have shown that a diet high in fruits (especially Ginger fruits) protect against cancer which may be due to the high level of antioxidant these fruits contain. These antioxidants are compound found in the juice and skin of fruits which help to protect the body against free radicals and therefore may also have a role to play in preventing heart related diseases, ageing and cancer (Kolo *et al.*, 2022).

2.7 Some Related Fruit Depulping Machines

Depulping is an agricultural processing equipment that is used to remove pulp or separating the pulp from shea nut. The fruit is the edible part of a plant, usually fleshy which is sweet and said to contain nutrients which are beneficial to human body (Ahouansou *et al.*, 2018). They are an important component of a healthy diet and if consumed daily in sufficient amounts, could help prevent major diseases such as Cardio Vascular Diseases (CVDs) and certain cancers (Houndonougbo *et al.*, 2020).

2.7.1 Locust bean depulping machine

The depuing of locust bean seeds is an important step in the processing of various locust bean derivatives and products. African locust bean, also known as *Parkia biglobosa*, is a widely consumed crop in Africa. The long pods of the locust bean contain small beans and sweet edible pulp, while the chaff is used as animal feed. The pulp of the locust bean is a source of a chocolate substitute, and is used to make fermented condiments such as "*Iru*" or "*dawadawa*", which are commonly used to flavor soups and stews in Nigeria (Ahouansou *et al*., 2018).

However, volume of the depulping stirring unit (Plate V) is an important factor in determining its efficiency and effectiveness in removing locust bean pulp from the seed. The unit operates by combining cutting, abrasion, and rubbing actions to remove the pulp. The paddle within the unit creates a cutting effect on the pulp through impact, while the clearance between the cylindrical sieve shell and the attached brushes on the paddles creates the desired abrasion and rubbing actions for the depulping operation (Olaoye, 2011).

The volume of the unit is related to its depulping capacity, which determines the amount of locust bean seeds that can be processed at a time. A larger volume can accommodate more seeds, which results in a higher depulping capacity. Therefore, a depulping stirring unit with a larger volume is generally more efficient and effective in removing locust bean pulp from the seeds, as it can process more seeds at once, resulting in a higher yield of depulped seeds (Olaoye, 2011).

However, the test results indicated that the depulping efficiency varied between 64 and 98 % and seed membrane damage and seed loss were less than 5 and 9.2 % respectively at 45 minutes soaking time and at 350 rpm depulping shaft speed. The maximum power requirement was 2.25 kW at a shaft speed of 550 rpm. The operating conditions of shaft speed at 350 rpm, 45 minutes soaking time indicated higher depulping efficiency, lower seed membrane damage and seed loss during depulping operation. Result of process performance showed that the final depulping process compared favorably with that of traditional method (Olaoye, 2011).

Plate V: Locust Bean Depulping Machine
(Source: Olaoye, 2011)

2.7.2 Bread fruit depulping machine

Bread fruit de-pulping machine is a mechanical device designed for cleaning of bread fruit seeds. The author developed a machine with a similar design to a batch agitator for this purpose. The machine is powered by a 1.5 KW electric motor and operates at a recommended shaft speed of 137 rpm. It comprises eight major components: the motor, hopper, speed reduction unit, screw conveyor, shearing plate, screw housing unit, paddle, and pumping/washing system. The machine's details and working principle can be found in the referenced works. To address issues such as high water consumption and generated noise, as well as to increase processing capacity, the machine consists primarily of four components: the hopper/depulping chamber, connector pipe, separator, and power system (Sobechukwu *et al.,* 2016).

2.7.3 Coffee bean depulping machine

The popularly known Coffee is a brewed drink which is prepared from roasted seeds of coffee beans that are gotten from berries of a particular type of coffea specie. The coffea species which coffee is extracted from is native to mainly Sudan and Ethiopia (in Africa), Mauritius, Comoros, Madagascar and the Indian Ocean. Coffee plants grow well within this area, which lies between the tropic of Cancer and the tropic of Capricorn, usually termed the bean belt or the coffee belt (Ogunjirin *et al.*, 2021). For many years, coffee, considered to be the world's most valuable export after rice, has remained one of the most acceptable and consumed food beverages with a huge health advantage (Abrhám *et al.*, 2021).

However, Coffee is an agricultural commodity with such tremendous growth in supply and demand has a lot of elements which affects its final quality (Buvaneshwaran *et al.*, 2022). These elements vary from the crop, variety, climate, cultivation, harvest and post-harvest operations. One of the major post-harvest operations which has impact on the quality of the coffee is depulping. Ogunjirin *et al.*, (2021) work highlighted the design, fabrication and working process of a coffee bean depulping machine, developed at the National Center for Agricultural Mechanization (NCAM) which was improved from an existing machine. The coffee depulping machine was operated by a prime mover running at 800 rpm after being soaked for two hours. Performance evaluation revealed that the machine had an average depulping efficiency of 96.6% with machine throughput of 4.67 kg/s. More importantly is the fact that the depulped coffee beans was not crushed by the machine which was an improvement over the initial prototype developed.

CHAPTER THREE

3. 0 MATERIALS AND METHODS

3.1 Materials

The construction of the machine involved the use of mild steel materials, with equipment such as a welding machine, angle irons, oxygen acetylene gas, drilling machine, tri square, hack saw, vice and electric hand grinder. Gbabo *et al*. (2016). The shea fruit was obtained from Gbodoti village in Edati Local Government Area of Niger state.

3.2 Design Methods

The following factors were considered in designing shea fruits depulping machine:

i. Availability of Construction Material: The availability of materials in local markets for fabrication is a very important factor that was considered in the design.

ii. Versatility of Machine Application: The design is done with the intention for it to be used for all shea nuts.

iii. Maintenance Consideration: The simplicity of the machine is such that it allows for easy maintenance by local artisans and farm machinery operators.

3.3 Design Calculations

3.3.1 Theoretical capacity

The assumed weight of the machine is 1000 kg of the shea fruits would be depulp in a day consisting of 8 h of work, therefore the theoretical capacity of the machine is 125 kg/h.

3.3.2 Determination of the diameter of the screw conveyor

The screw conveyor is a major component of the machine unit. It is acted upon by the weights of the pulley and screw thread. In operation, the screw conveyor conveys and squeezes the endothermal part of the shea nuts by bruise force. Therefore, in order to safeguard against bending and torsional stresses, the diameter of the shaft is determined from the Equation (3.1) given by Khadatkar and Mathur (2022) as:

$$d_s^3 = \frac{16}{\pi\delta_o}\sqrt{(k_b m_{b)^2} + (k_t m_t)^2} \quad (3.1)$$

Where:

d_s = diameter of screw auger (mm)

δ_o = allowable shear stress (55 x 10^6 N/m^2 for shaft without keyway)

k_b = combined shock and fatigue factor applied to bending moment

k_t = combined shock and fatigue factor applied to torsional moment

k_b = 1.5 and k_t = 1.0 (for load applied gradually)

m_b = maximum bending moment kNm

m_t = maximum torsional moment kNm

3.3.3 Determination of the throughput

To effectively determine the sizes of the screw, the throughput capacity is important to ensure that the material pressure exerted on the screw is within design. The throughput flow rate is in Equation (3.2) as given by Ani *et al*., (2020) as;

$$\mathrm{Q} = \frac{\mathrm{m}}{\mathrm{t}} \quad (3.2)$$

Where:

Q = throughput capacity (kg/h)

m = assumed mass of the shea fruit 125kg/h

t= time taken (h)

3.3.4 Determination of the volume flow rate

The volumetric flow rate is the volume conveyed by the screw per unit time. It is also an important parameter in screw design, showing the amount of materials flowing through the working chamber of the machine at a time. It can be calculated using the Equation (3.3) given by (Saha *et al.*, 2023)

$$V = \frac{Q}{\rho} \tag{3.3}$$

Where:

ρ is the density of the shea fruit (356.2 kg/m^3) (Saha *et al.*, 2023)

V is the volumetric flow rate (m^3/s)

Q is the throughput capacity (kg/s)

3.3.5 Determination of speed of screw auger

The quantity of the shea fruit depulped by the machine depend on the speed of the screw auger which determine the free flow of materials inside the barrel without sticking to the barrel walls and without causing too much breakage of the shea nut as shown in Equation (3.4) Mamatov *et al*. (2021)

$$C_{th} = \frac{\pi(D^2 \times S \times Q)}{4} \tag{3.4}$$

Making S subject of the formula;

$$S = \frac{4 \times C_{th}}{[\pi \times D^2 \times Q]} \tag{3.5}$$

Where;

C_{th}=Theoretical capacity (kg/h)

D= the diameter of the screw (mm)

S = speed of the screw auger (rpm)

Q = the Throughput rate of the materials (kg/h)

3.3.6 Determination of pressing area and pressure developed by the auger

The auger pressure and pressing area are designed to provide efficient bruise forces required to remove the pulp parts of the shea nuts. The pressing area and the pressure developed by the auger were determined from Equations (3.5) and (3.6) respectively given by Bereziuk *et al*. (2023)

$$A_p = \pi D_m n h \qquad (3.6)$$

Where:

A_p = Pressing area (mm^2)

h = Screw depth at the maximum pressure (discharged end), mm;

n = number of threads

D_m = diameter of the shaft (mm)

3.3.7 Pressure developed by the auger

The pressure developed by auger

$$P_r = \frac{W_f}{A_P} \qquad (3.7)$$

Where:

P_r = pressure developed by the auger, (N/mm^2)

A_p = Pressing area (mm^2)

W_f = Force acting on the screw auger (N)

To determine force acting on the screw auger, assuming a torque of 540 Nm, and using the same values for the diameter of the auger (20 mm) and the coefficient of friction (0.3). The force acting on the screw auger can be calculated using the formula given in Equation (3.8) as stated by Bulgakov *et al* (2022).

$$F = \frac{T_q}{R \times C_f} \tag{3.8}$$

Where:

F = Force (N)

R = Radius is half of the diameter, or 10 mm = 0.01 m

T_q = Torque (N)

C_f = Coefficient of friction

3.3.8 Determination of pressure developed by auger on the barrel

The pressure developed by the auger on the barrel can be determined by considering the forces acting on the material being bruised through the barrel. The pressure developed on the barrel guides on the appropriate materials for the barrel selection. The pressure to be withstood by the barrel was determined from Equation (3.9) and (3.10) Kadurumba, (2020);

$$P_b = \frac{2t\delta_a}{Di} \tag{3.9}$$

Where:

P_b = pressure on the barrel (N/m^2)

t = thickness of the barrel (mm)

D_i = the inside diameter of the barrel (mm)

δ_a= allowable stress, ($\delta_a = 0.27\delta_o$) (Nm^2)

Allowable stress for barrel can be calculated using equation;

$$\delta_a = \ (\delta_a = 0.27\delta_o) \qquad (3.10)$$

Where:

δ_a= allowable stress, (N/m^2)

δ_o= the yield stress for mild steel (N/m^2)

$\delta_a = 0.27\delta_0$

$\delta_0 = 200\ N/m^2$

Substituting the values into the Equation (3.8);

3.3.9 Determination of the screw pitch

The screw pitch serves the purpose of providing enough clearance and assisting in the cutting or shearing of the material that is conveyed between the screw and the wall of the barrel. The pitch of the screw can be calculated using the formula given in Equation (3.11) (Kadurumba, 2020):

$$P = \pi \times \frac{D}{N_t} \qquad (3.11)$$

Where:

P = pitch of the screw (mm)

D = screw diameter (mm)

N_t = number of threads

D = 20 mm

N_t = (Assumed number of thread= 3)

3.2.10 Determination of length of the barrel

The length of the barrel is a crucial factor that impacts the extrusion process. It is recommended that the diameter of the barrel be slightly greater than that of the screw to enable smooth material flow. The barrel length can be calculated using the formula given Equation (3.12) by Fikus *et al.* (2022) as;

$$L_b = Ls + 4 \times D \tag{3.12}$$

Where:

L_b = barrel length (mm)

L_s = screw length (mm)

D = screw diameter (mm)

Assuming a screw length of 300 mm,

3.3.11 Determination of the power requirement for depulping

The design for electric motor output power enables appropriate selection of a motor with enough power to start and run the machine at full load. The power requirement of the machine for depulping of the kernel out of the shea nuts and power required to drive all other units, can be calculated using the Equation (3.13) given by Bulgakov *et al.* (2022)

$$P_e = 4.5 \times Q_{vc} \times l_s \times \rho \times g \times F \tag{3.13}$$

Where:

P_e = power requirement for depulping (hp)

Q_{vc} = volumetric capacity (kg/m^3)

l_s = length of screw shaft, mm

ρ = density of the material, kg/m^3

g = acceleration due to gravity, N/m^2

F = the material factor.

3.3.12 The drive system

V-belt and pulley arrangement were adopted in this study to transmit power from the electric motor to the shaft of the depulping unit. The main reasons for adopting the v-belt drive are its absorbed shocks thereby mitigating the effect of vibratory forces (Olaoye, 2011).

i. **Determination of the machine pulley diameter**

The pulley provides the simple way to transfer the power from one shaft to another, the pulley diameter for depulping screw as shown in Figure 3.1 is computed using the formula given in Equation (3.14 and 3.15) as cited (Olaoye, 2011).

$$N_1D_1 = N_2D_2 \tag{3.14}$$

Making D_2 the subject of formula;

$$D_2 = \frac{N_1D_1}{N_2} \tag{3.15}$$

Where:

D_1 = Diameter of electric motor pulley, 80 mm

N_1 = Speed of motor, 1500 rpm

D_2 = Diameter of depulping Screw pulley, mm

N_2 = Assumed Working Speed of depulping screw unit, 1000 rpm

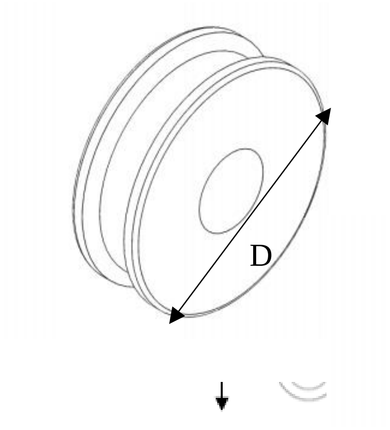


Figure 3.1: Pulley

i. Belt length

Well calculated belt length is necessary to avoid reduced tension of the belt and ensure efficient power transfer to the depulping unit. The Belt length for the depulper drive can be determined using the formula as expressed in Equation (3.16) Etoamaihe *et al*. (2022);

$$X = 2C + 1.57(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4C} \quad (3.16)$$

Where:

X = belt length, m

C = Center distance between pulleys, 350 mm

D_1 = Pitch diameter of driver pulley, 50 mm

D_2 = Pitch diameter of driven pulley, 120 m

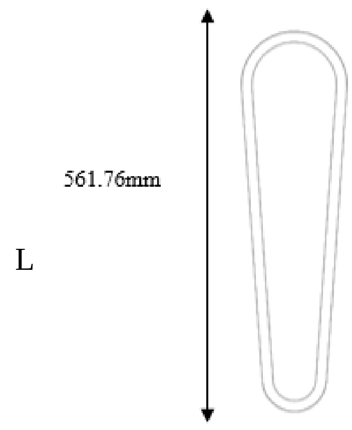


Figure 3.2: V-Belt

ii. Belt tension

The belt tension is required to provide proper contact between belt and pulley, it is measured in newton (N). given in Equation (3.17) Khadatkar and Mathur (2022) as

$$T = \frac{W \times g \times (\mu \times \tan\theta)}{2 \times \cos\theta} \quad (3.17)$$

Where:

T = Tension (N)

W_e= load that can be conveyed by the screw (kW)

g = acceleration due to gravity= 9.8 m/s^2

θ = angle of contact= 15°

μ = Assuming coefficient of friction between belt and pulley = 0.5

3.2.13 Selection of bearing

The basis for the selection of bearing size according to Gary *et al.* (1984) are the radial loading (W_r), thrust or axial load (W_a), the speed (N), required life (L_R) and the vibration condition. The dynamic radial equivalent load for bearing on the depulping shaft is expressed in Equation (3.18) Khurmi and Gupta (2005) as;

$$W_E = X.V\,W_r + YW_a \tag{3.18}$$

Where;

$W_r = Radial\ Load\ (kN)$

W_a = Axial load or Thrust (N)

To find the radial load;

$$W_r(Radial\ Load) = \frac{P}{2\pi Nr} \tag{3.19}$$

3.3.14 Determination of height of the feed hoppers

The feed hoppers is trapezoidal in shape in order to accommodate enough fruits and gradually introduce portions of the by gravity into the depulping compartments. Supposing the hopper is to hold 30 kg of shea nuts and the bulk density of shea fruit is 356.2 kg/m^3.

The height of hopper can be calculated using the expression in Equation 3.20

$$V = \frac{m}{\rho} \tag{3.20}$$

Where:

Bulk density = 356.2 kg/m^3

Mass of the shea fruit = 30 kg

V = volume of hopper, D = height of hopper, C = width of upper end, A = hopper length of hopper, B = lower length

A = 400 mm

B = 200 mm

C = 300 mm

D =?

To calculate the height of the hopper;

The average height of the hopper:

Calculate the height of a trapezoidal hopper which is assumed to hold 30 kg of shea fruit, length and width of the hopper is 300 mm and 200 mm respectively,

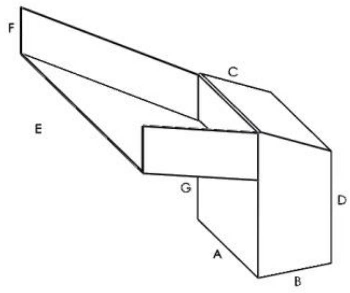


Figure 3.3: Hopper

3.4 Fabrication of Machine

The machine was fabricated using mild steel materials. Available necessary workshop equipment such as welding machine to join the sheet, angle iron and rod with the aid of the electrode, vice for holding then work piece and electric hand grinder for leveling and smoothening welded and rough surfaces of the machine.

3.5 Description of Machine Parts

Shea fruit depulping Machine is composed of the following components parts;

i. Hopper: The hopper (Plate VI) holds the shea nuts temporarily and discharge the materials gradually with the aid of gravity into the depulping unit of the machine. It is constructed with 1.5mm mild steel and actual height 670.6 mm while the width 400 mm by 432 mm. The hopper is trapezoidal which was carefully selected considering the nature of the materials.

Plate VI: Hopper

ii. Barrel: The barrel (Plate VII) is the cylindrical/hollow chamber in which the auger operates, it houses the screw shaft that presses the shea fruit against it wall to depulp the shea fruit as it moves through the hollow barrel container. The barrel is constructed with 1.5 mm steel gauge, it has inside and outlet diameter 304 mm and 800 mm. This is the unit where major depulping activities occurs.

Plate VII: Barrel

iii. Nut Outlet: This is located at the rear end of the barrel (Plate VIII); it is the opening through which the kernel is been discharged after removal of pulp and it has calculated width of 266 mm and length 304.8mm. It is also fabricated using mild containing an outward tray.

Plate VIII: Kernel Outlet

iv. Pulp Outlet: The pulp (Plate IX) extracted fall under the perforated screen and it's been discharged through the pulp outlet located at the front of the machine. It is also constructed with mild steel because the pulp is not for direct consumption and has outward length that guide the pulp into the collector.

Plate IX: The Pulp outlet

v. Frame: The frame (Plate X) is a rigid stationary body fabricated using rectangular angle iron 250 mm × 250 mm × 150 mm, it main purpose is to provide resting support and stability for the machine.

Plate X: The frame

vi. Auger: The auger (Plate XI) is the helical screw shaft that is made of mild steel, quarter rod and square rod which rotates inside a cylindrical chamber called barrel. The auger bruised and pushing the material or kernels along the length of the barrel to the kernels outlet. The maximum outer diameter is 190 mm to give clearance between screw and barrel. The screw auger is carried on a solid shaft of 25 mm which is driven by a pulley.

Plate XI: The Auger

vii. Pulley: pulley (Plate 3.7) is the cylindrical or circular wheel which transmit power and motion from one part of the machine to another and it calculated diameter is 250 mm.

Plate XII: The Pulley

3.6 Performance Evaluation of the Machine

The shea fruit depulping machine was evaluated for the following parameters; Actual capacity of the machine, Depulping Efficiency, Pulp loses and Kernel breakage. These parameters were evaluated using the varying i. speed of the ma chine ii. moisture content of the shea nuts and iii. feed rate.

a. **Actual capacity of the machine**

Actual capacity of the machine is the quantity of the materials (shea fruit) that is been depulp per hour. It is expressed in kg/h as shown in Equation (3.20) Khurmi and Gupta (2005);

$$C_a = \frac{Q}{t} \tag{3.20}$$

Where;

C_a = is the actual capacity of the machine (kg/h)

Q = is the quantity of shea fruit depulped in kg

T = is the time taken for depulping in h

b. **Depulping efficiency**

This is the degree at which the pulps were removed from the fruit or the ratio of the quantity of the shea fruit completely depulped to the total quantity of shea fruit. It is mathematically expressed employing Equation (3.21);

$$D_e = \frac{D}{U} \tag{3.21}$$

Where:

D_e=the depulping efficiency (%)

D=the completely depulped shea fruit (kg)

U=the partially depulped shea fruit (kg)

c. **Pulp loses**

The quantity of pulp loses or stick to the depulping chamber due to high moisture content of shea fruit. It is mathematically expressed in Equation (3.22);

$$P_L = \frac{Q_t - (Q_{kol} + Q_{pd})}{Q_t} \times 100 \tag{3.22}$$

Where:

P_L= the depulp loses (%)

Q_t = the total quantity of shea fruit (kg)

Q_{pd} = the quantity of pulp discharged (kg)

Q_{kol} = the quantity of nut discharged at outlet (kg)

d. Kernel breakage

The percentage kernel breakage is the ratio of the quantity of kernel that brock to the whole nut of the shea fruit at given time. It is mathematically expressed in Equation 3.23;

$$K_b = \frac{Q_b}{Qub} \quad (3.23)$$

Where:

K_b = the percentage nut broken (%)

Q_b= Quantity of nut kernel (kg)

Q_{ub}= Total quantity of nut processed (kg)

3.7 Design of Experiments

The three variables (Machine speed, Moisture Content and Feed rate), three level factorial design (N = 3 provides the frame work for the experiment. D-optimal response surface, the experimental design employed was a response surface designed according to the principle of factorial experiment. The three levels of speeds were assigned to main plot as shown in Table 3.1, the three levels of moisture content and three levels of feed rates would be confounded. The data obtained would be subjected to analysis of variance using design Expert software.

Table 3.1: Independent Factors

Factors	Levels		
Moisture content (%)	15	20	25
Speed of Machine (rpm)	500	750	1000
Feed rate (kg/h)	20	40	60

3.8 Cost Analysis for the Fabrication of a Shea Fruit Depulping Machine

The total production cost was estimated from the addition of the materials costs (all the parts used either purchased or fabricated) (Table 3.2), labour costs (workers or manufacturer used to assemble and operate the machine and transportation) and manufacturing overhead (utility) costs. The cost of workmanship, ingredients used for test, running and standardization of the fabricated single screw depulping machine were estimated for one hundred and eighty thousand naira (₦170,400).

3.9 Bill of quantity

The breakdown of engineering bill of material estimate for the construction of shea fruit depulping machine is shown in table 3.2.

Table 3.2: Bill of engineering measurement and evaluation

S/N	Materials	Quantity	Rate	(N)
	Amount			
1.	Square rod	1 length	3,000	3,000
2.	Angle iron (1.5”)	2 lengths	5,000	10,000
3.	Mild steel plate	3 sheet	12,000	36,000
4.	1.5” pipe	1 length	4,000	4,000
5.	Bearing	2	2,500	5,000
6.	Motor 2 hp	1	68,000	68,000
7.	Bolt and Nuts	2 dozen	1,200	2,400
8.	Paint	1 litre	3,000	3,000
9.	Pulley	2m	4,000	4,000
10.	Labour cost			
35,000				
	Total			**170,400**

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Effect of Speed on the Machine Performance

4.1.1 Effect of speed on the actual capacity of the machine

The result of evaluation showing effect of speed on the actual capacity of the machine is shown in Figure 4.1. At 500 rpm, the actual capacity of the machine is lowest across all three moisture levels analyzed (15 %, 20 %, and 25 %). As the machine speed increases from 500 to 750 rpm, there is a steep decrease in actual capacity. However, beyond 750 rpm, the actual capacity of the machine gradually increases up to a maximum of 22.75 kg/h at 1000 rpm. This suggests that there is an optimal machine speed range for achieving maximum actual capacity, and that operating the machine at speeds beyond this range may result in lower actual capacity. Furthermore, the actual capacity varies across different moisture levels. At 15 % moisture content, the actual capacity is lowest across all machine speeds. However, at 20 % and 25 % moisture content levels, the actual capacity increases with increasing machine speed, reaching a maximum at 1000 rpm. machine operates at a higher speed; it can potentially complete more deployments within a specific period. This can increase the overall capacity of the machine. Faster deployment times mean that more tasks can be executed, leading to higher productivity and potentially greater output (Sobechukwu *et al.,* 2016).

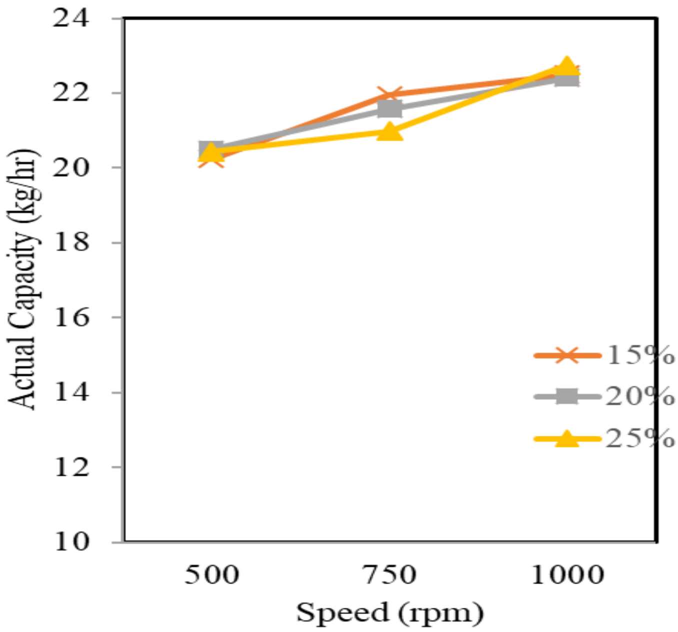


Figure 4.1: Graph of Effect of Speed on the Actual Capacity of the Machine

4.1.2 Effect of speed on the depulping efficiency of the machine

The effect of speed on the depulping efficiency of the machine at three moisture levels as shown in Figure 4.2 indicate that the depulping efficiency of 87.5 % is higher at the highest moisture level of 25 % and machine speed of 500 rpm. Although, the depulping efficiency of the Shea fruit is just slightly lower at 15 % and 20 % as 78.5 % and 81 % respectively. Increasing the speed of the machine to 750 rpm, the depulping efficiency at moisture level of 15 % and 20 % also increased to 85 % and 80 % respectively while efficiency of the machine at 25 % moisture level decreased to 83 %, indicating that 15 % moisture level proves to be more efficient at speed 750 rpm. Furthermore, increasing the machine speed to 1000 rpm result in slight reduction in the efficiency of the pulp removed from the Shea nuts at 15 % moisture level while that of 25 % moisture level increases slightly. These changes in the efficiency of the machine with speed indicates that machine speed and moisture level affect the efficiency of the depulping.

According to Olaoye (2011) the locust bean depulping machine, the result shows that the increase in depulping efficiency from speed 150 rpm to 350 rpm clearly indicated that greater energy impact was induced on the locust bean pulp. Increased speed beyond 350 rpm reduces the depulping efficiency this implied that excessive energy impacted on the pulp causes on Maximum pulp removal efficiency of 78.1 % was achieved with screw speed of 60 rpm. Seed separation from the pulp was carried out by adding different chemicals. Use of sodium hydroxide and potassium hydroxide produced seed separation up to 99 %.

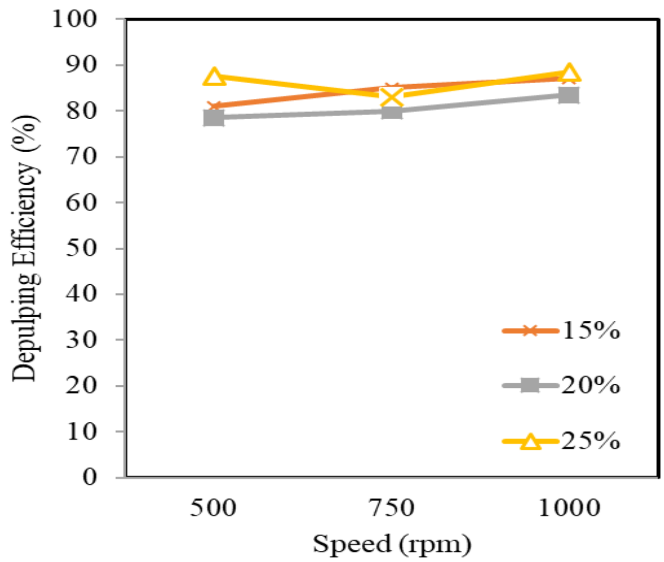


Figure 4.2: Graph of Effect of Speed on the Depulping Efficiency of the Machine

4.1.3 Effect of speed on the kernel breakage of the machine

The result of the effect of speed of the depulping machine on the kernel breakage is sown in Figure 4.3. At 15 % moisture content, the percentage kernel breakage is highest across all three machine speeds analyzed (500, 750, and 1000 rpm). As the moisture content increases from 15 % to 25 %, there is a decrease in % kernel breakage across all machine speeds. This suggests that increasing moisture content can help to reduce kernel breakage during the depulping process. At 500 rpm, the % kernel breakage is highest across all three moisture levels analyzed (15 %, 20 %, and 25 %). As the machine speed increases from 500 to 750 rpm, there is a decrease in % kernel breakage. However, beyond 750 rpm, the % kernel breakage increases slightly up to 1000 rpm.

This is in line with findings by Akinfiresoye *et al*. (2020) that higher speeds in the depulping machine can generate stronger impact forces as the nuts come into contact with the internal components or other nuts. These impact forces in relation to the moisture content of the nut can increase the risk of nut breakage.

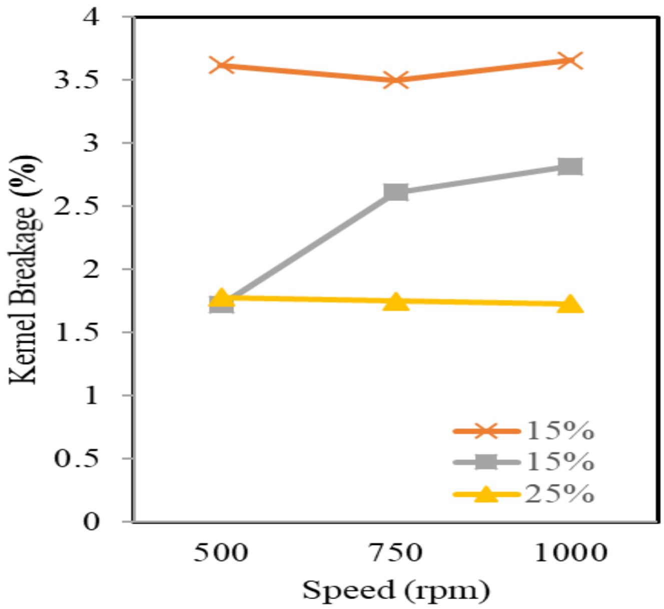


Figure 4.3: Graph of Effect of Speed on the Kernel Breakage of the Machine

4.1.4 Effect of speed on the pulp loss of the machine

The result of test on the effect of speed on the % pulp loss as shown in Figure 4.4 indicate that at a moisture content of 15 %, there is a slight increase in pulp loss from 7.5 % at 500 rpm to 8.0 % at 750 rpm, while a decrease to 8.7 % at 1000 rpm was observed. At a moisture content of 20 %, there is a decrease in pulp loss from 9.5 % at 500 rpm to 8.65 % at 750 rpm and no further significant decrease at 1000 rpm as indicated in table 4.1. At a moisture content of 25 %, there is a decrease in pulp loss from 9.76 % at 500 rpm to 9.7 % at 750 rpm and a further decrease to 9.55 % at 1000 rpm. Consequently, these results suggest that increasing the speed of the machine can be an effective way to reduce pulp loss during the production process, especially at higher moisture content levels. However, it is important to note that there may be other factors at play, such as the specific type of machine being used or variations in the raw materials being processed, which could affect the results.

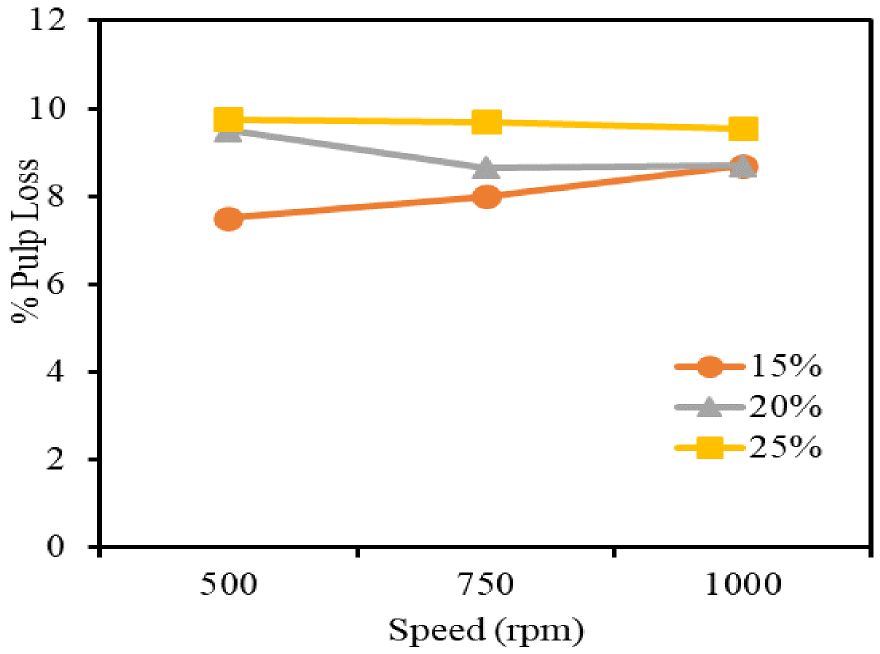


Figure 4.4: Graph of Effect of Speed on the Pulp Loss of the Machine

Table 4.1: ANOVA for Response Surface

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	4.991791	9	0.554643	1.18183	0.3966	not significant
A-Speed	1.093504	1	1.093504	2.33003	0.1579	
B-Moisture	2.397191	1	2.397191	5.107917	0.0474	
C-Feed rate	0.783126	1	0.783126	1.668679	0.2255	
AB	0.157852	1	0.157852	0.336349	0.5748	
AC	0.377474	1	0.377474	0.804319	0.3909	
BC	0.023235	1	0.023235	0.04951	0.8284	
A^2	0.525657	1	0.525657	1.120066	0.3148	
B^2	0.201613	1	0.201613	0.429595	0.5270	
C^2	0.373238	1	0.373238	0.795293	0.3935	
Residual	4.693089	10	0.469309			
Lack of Fit	0.440889	5	0.088178	0.103685	0.9868	not significant
Pure Error	4.2522	5	0.85044			
Cor Total	9.68488	19				

4.2 Feed Rate on the Machine Performance

4.2.1 Effect of feed rate on the actual capacity of the machine

The result of effect of feed rate on the actual capacity of the machine is shown in Figure 4.5. It is observed that the actual capacity of the machine is affected by the machine feed rate and the moisture content. At 15 % and 20 % moisture content, the actual capacity of the machine is highest at a feed rate of 40 kg/h, while at 25 % moisture content, the actual capacity is highest at a feed rate of 60 kg/h. This suggests that the optimal feed rate for maximizing actual capacity may vary depending on the moisture content of the Shea fruit being depulped. At all moisture levels, there is a general trend of decreasing actual capacity as the machine feed rate is increased from 20 to 60 kg/h. However, this trend is not consistent across all moisture levels, as there are instances where the actual capacity increases as the feed rate increases (e.g. from 10.86 to 11.97 at 20 % moisture content). The overall effect is similar to the finding by Sobechukwu *et al.* (2016).

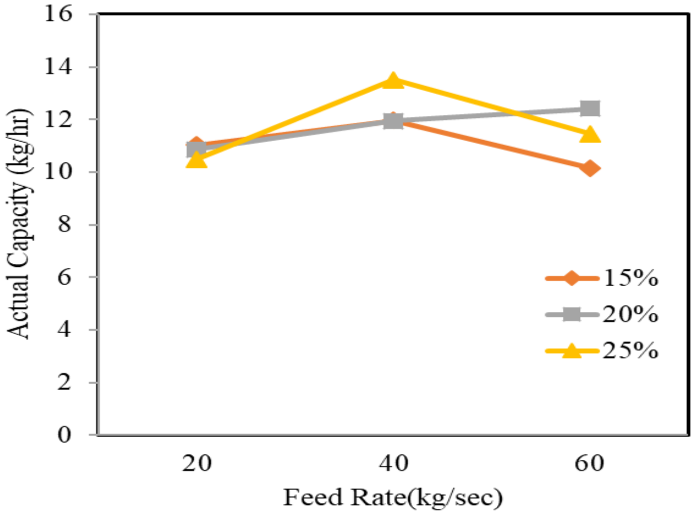


Figure 4.5: Graph of Effect of Feed Rate on the Actual Capacity of the Machine

4.2.2 Effect of feed rate on the depulping efficiency of the machine

The effect of feed rate on the depulping efficiency of the machine shown in Figure 4.6 depict that efficiency of 87.5 % is higher at feed rate of 20 kg/min and moisture 25 % level and lowest efficiency of 81.25 % for 20 kg/min feed rate for 15 % moisture. Effect of feed rate on the depulping efficiency shows similar pattern for Shea nuts at 15 % and 20 % moisture levels, there is slight increases in the efficiency from 81.25 % to 87.5 % and 85 % to 88 % for 15 % and 20 % moisture levels respectively as the feed rate increase from 20 kg/min to 60 kg/min. Conversely, the effect of feed rate on the Shea fruit at 25 % moisture level indicate decrease from 87.5 % to 76 % as the feed rate is increased from 20 kg/min to 40 kg/min, however further increase in feed rate leads to increase in the depulping efficiency of the machine to 89 %. This increase is due to sufficient pressure that is required to bruise the pulp and force the kernel out of the barrel. The overall effect is also similar to the finding by Abrhám *et al.* (2021).

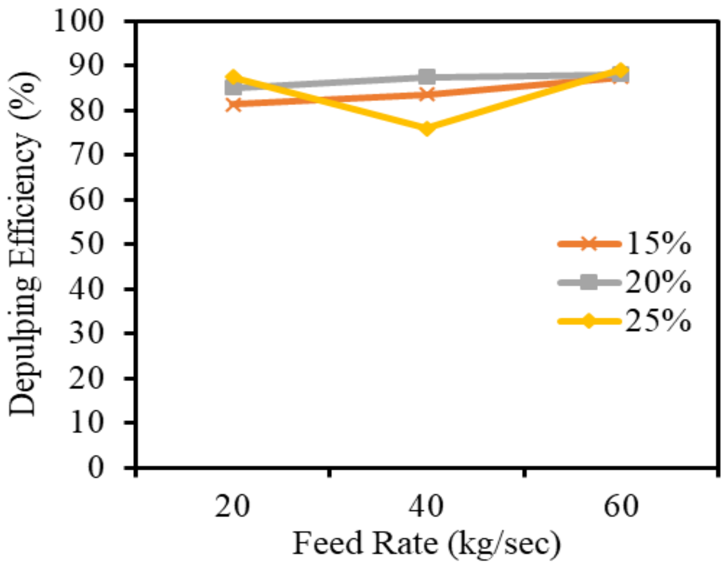


Figure 4.6: Graph of Effect of Feed Rate on the Depulping Efficiency of the Machine

4.2.3 Effect of feed rate on the kernel breakage of the machine

The result of the kernel breakage as it been affect by machine feed rate of 20 kg/min, 40 kg/min and 60 kg/min at three moistures levels 15 %, 20 % and 25 % is shown in Figure 4.7. The kernel breakage indicates a declining trend for all the three moisture level indicating the moisture. It can be observed that as the feed rate of the Shea fruit through the depulping machine increases from 20 to 60 kg/h, the corresponding kernel breakage decreases. This inverse proportionate relationship between feed rate and kernel breakage indicates that a higher feed rate leads to lower kernel breakage during processing. This trend is consistent across all three moisture content levels analyzed (15 %, 20 %, and 25 %). It is also noteworthy that the kernel breakage decreases as the moisture content of the Shea fruit increases, which suggests that the moisture content plays an important role in minimizing kernel breakage during the depulping process. This finding is consistent with the previous observation that the efficiency of the depulping process is more affected by moisture content than machine speed.

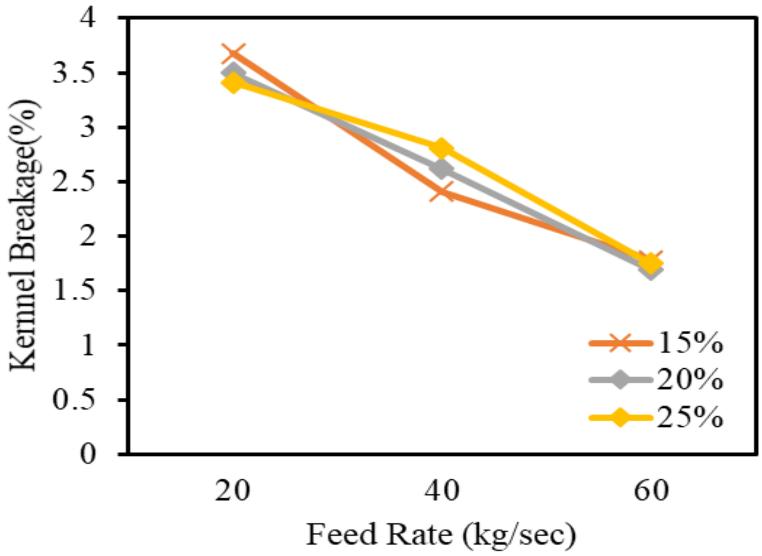


Figure 4.7: Graph of Effect of Feed Rate on the Kernel Breakage of the Machine

4.2.4 Effect of feed rate on the pulp loss of the machine

The loss in the pulp discharged increases with the increasing feed rate of the machine, loss in the pulp indicate similar pattern across all the moisture levels as shown in Figure. 4.8. The loss of the Shea fruit pulp at moisture 20 % moisture level increases from 8.03% to 9.76 % with increasing feed rate from 20 kg/min to 60 kg/min. At 40 % moisture level, the percentage pulp loss increases from 8.0 % to 9.5 % as the feed rate increases from 20 kg/min to 60 kg/min, while Shea pulp loss for 25 % moisture level result to pulp loss increases from 7.65 % to 9.7 %. However, moisture content of the Shea fruit does not leads to pulp loss, only fee rate proportionately affect the losses in the pulp discharged from the depulping machine.

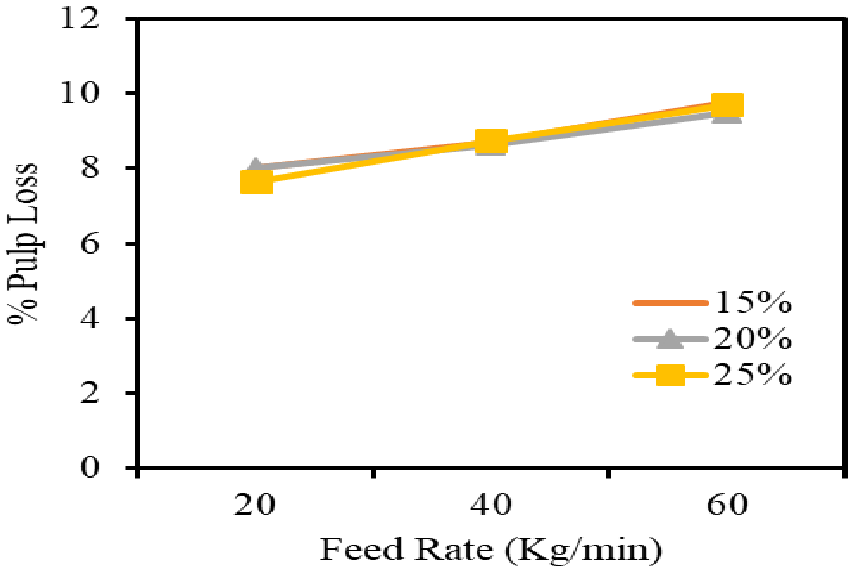


Figure 4.8: Graph of Effect of Feed Rate on the Pulp Loss of the Machine

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions were drawn from the study;

The Shea fruit depulping machine was successfully designed to depulp Shea fruit with actual capacity of 149.9 kg/h.

The major components fabricated for the successful working of the shea fruit depulping machine include the hopper, pulp mesh, screw auger, pulp outlet, kernel outlet, supporting frame.

The performance evaluation of the machine reveals that the effective actual capacity of the machine of 149.9 kg/h, the depulping efficiency of 87.5 %, low kernel breakage of 3.5 %, and pulp loss of 9.55 % at the highest moisture level of 24.25 % and machine speed of 874.98 rpm.

5.2 Recommendations

i. Increase moisture content: To achieve higher depulping efficiency, it is recommended to increase the moisture content of the Shea fruit from 15 % to 23 %. This can be achieved by using appropriate pre-treatments such as steam or water soaking.

ii. Optimize machine speed: increasing the speed of the machine beyond 750 rpm can improve efficiency, it is recommended to optimize the speed within the range of 500-750 rpm to avoid steep decreases in efficiency. The optimal speed may vary depending on the specific design of the machine, but the general trend should be observed.

iii. Control feed rate: To minimize kernel breakage during processing, it is recommended to control the feed rate of the machine. Increasing the feed rate can lead to lower kernel breakage, but this should be optimized to avoid compromising depulping efficiency.

Therefore, the feed rate should be carefully monitored and adjusted accordingly to balance efficiency and quality.

5.3 Contribution to Knowledge

A shea fruit depulping machine has been developed and evaluated. The best working conditions for optimal speed and performance of the shea fruit depulping machine has been established.

REFERENCES

Abdel-Razek, A. G., Abo-Elwafa, G. A., Al-Amrousi, E. F., Badr, A. N., Hassanein, M. M. M., Qian, Y., & Rudzińska, M. (2023). Effect of Refining and Fractionation Processes on Minor Components, Fatty Acids, Antioxidant & Antimicrobial Activities of Shea Butter. *Foods*, *12*(8), 1626.

Abdul-Mumeen, I., Beauty, D., & Adam, A. (2019). Shea butter extraction technologies: Current status & future perspective. *African Journal of Biochemistry Research*, *13*(2), 9-22.

Abidemi, S. A., & Hamilton-Amachree, A. (2021). Elemental Composition & Proximate Analysis of Shea Butter Sold in Swali Market, Yenegoa, Nigeria. *International Journal of Environment, Agriculture & Biotechnology*, *6*, 1.

Abrhám, J., Vošta, M., Čajka, P., & Rubáček, F. (2021). The specifics of selected agricultural commodities in international trade. *Agricultural & Resource Economics: International Scientific E-Journal*, *7*(1868-2021-1373), 5-19.

Adesope, A. A. A., Fatoki, O. A., & Oguntoye, T. O. (2022). Value Chain & Profitability Analysis of Shea Butter Production in Kwara State, Nigeria. *Journal of Agroforestry & Environment*, *15*(2), 91-97.

Afandi, N., & Sahudin, S. (2022). Natural active ingredients used in topical cosmetic formulations for antiageing: a systematic review. *International Journal of Pharmaceutical, Nutraceutical & Cosmetic Science (IJPNaCS)*, *5*(1), 67-78.

Afful, N. T., Abdulai, I., Azu, E., Elegba, W., Annor, C., Akama, C., & Amoatey, H. M. (2022). In vitro regeneration of *Vitellaria paradoxa* from shoot tip explants. *BioTechnologia*, *103*(1), 71-79.

Ahouansou, R. H., Bagan, G. C., Agbobatinkpo, P. B., Sanya, E. A., Vianou, A. C., & Hounhouigan, D. J. (2018). Effects of Active Grids Gap's Adjustment on Technical Performances of a Power-Driven Dehuller Devised for African Locust Beans Parkia Biglobosa. *Research Journal of Engineering & Technology*, *9*(3), 241-252.

Akatwetaba, D., Egeru, A., & Mugonola, B. (2018). RUFORUM Working Document Series (ISSN 1607-9345), No. 17 (2): 524-532. Available from http://repository. ruforum. org.

Akinfiresoye, W. A., Akintade, A. A., & Fasoyin, S. A. (2020). Development of African Locust Bean (Parkia Biglobosa) Depulping Machine. *European Journal of Engineering & Technology Research*, *5*(10), 1174-1178.

Alao, A. J., Fasola, A. A., Olateju, B. O., Amuda, A. J., Olatunji, O. O., Shittu, M. D., & Okunlola, D. O. (2021). Blood Profile & Selected Organ Histopathology of Sheep Fed Shea Cake (*Vitellaria paradoxa*) Meal. *Journal of Advances in Biology & Biotechnology*, *24*(7), 46-56.

Aleza, K., Villamor, G. B., Nyarko, B. K., Wala, K., & Akpagana, K. (2018). Shea (*Vitellaria paradoxa* Gaertn CF) fruit yield assessment & management by farm households in the Atacora district of Benin. *PloS one*, *13*(1), e0190234.

Ali, A. D., Ior, L. D., Dogo, G. A., Joshua, J. I., & Gushit, J. S. (2022). Ethnobotanical Survey of Plants Used as Biopesticides by Indigenous People of Plateau State, Nigeria. *Diversity*, *14*(10), 851.

Amoako, E. E., & Gambiza, J. (2021). Effects of fire on the population structure & abundance of Anogeissus leiocarpa & *Vitellaria paradoxa* in a West African savanna parkland. *Acta Oecologica*, *112*, 103745.

Ani, J. U., Akpomie, K. G., Okoro, U. C., Aneke, L. E., Onukwuli, O. D., & Ujam, O. T. (2020). Potentials of activated carbon produced from biomass materials for sequestration of dyes, heavy metals, & crude oil components from aqueous environment. *Applied Water Science*, *10*, 1-11.

Aneni, T. I., Adaigbe, V. C., Eziashi, E. I., & Esiegbuya, O. D. (2020). Insect Pest Management of Post Harvest Shea Fruits in Storage. *International Journal of Scientific Food Agriculture*, *4*, 330-337.

Animasaun, D. A., Oyedeji, S., Olorunmaiye, K. S., Azeez, M. A., Tijani, I. A., & Morakinyo, J. A. (2019). Morpho-chemical divergence & fatty acid profile of shea tree seeds (*Vitellaria paradoxa*) collected from different locations in Kwara State, Nigeria. *Acta Botanica Croatica*, *78*(1), 17-24.

Asare, E. K., Avicor, S. W., Dogbatse, J. A., & Anyomi, E. W. (2019). Occurrence of mistletoes on shea trees in Northern Ghana. *African Crop Science Journal*, *27*(4), 679-686.

Baiyeri, P. K., Ugese, F. D., & Nwobodo, C. E. (2019). Diversity, food, nutrition & medicinal importance of some selected less-known African indigenous tropical plant species: advocacy for global research attention. *CABI Reviews*, (2019), 1-12.

Balkrishna, A., Singh, S., Srivastava, D., Mishra, S., Sharma, S., Mishra, R., & Arya, V. (2023). A systematic review on traditional, ayurvedic, & herbal approaches to treat solar erythema. *International Journal of Dermatology*, *62*(3), 322-336.

Bereziuk, O. V., Savulyak, V. I., Kharzhevskyi, V. O., & Vishtak, I. V. (2023). Dependence of the wear rate on the microhardness of the coating of the auger hehydration in a garbage truck for municipal solid waste. *Problems of Tribology*, *28*(2/108), 56-61.

Bulgakov, V., Olt, J., Ivanovs, S., Trokhaniak, O., Gadzalo, J., Adamchuk, V., & Arak, M. (2022). Research of a contact stresses in swivel elements of flexible shaft in screw conveyor for transportation of agricultural materials.

Buvaneshwaran, M., Radhakrishnan, M., & Natarajan, V. (2022). Influence of ultrasound-assisted extraction techniques on the valorization of agro-based industrial organic waste–A review. *Journal of Food Process Engineering*, e14012.

Chen, J., Lin, S. H., & Wong, C. S. (2019). Oral shea nut oil triterpene concentrate supplement ameliorates pain & histological assessment of articular cartilage deterioration in an ACLT injured rat knee osteoarthritis model. *PLoS One*, *14*(4), e0215812.

Cheng, S., Ashley, J., Kurleto, J. D., Lobb-Rabe, M., Park, Y. J., Carrillo, R. A., & Özkan, E. (2019). Molecular basis of synaptic specificity by immunoglobulin superfamily receptors in Drosophila. *Elife*, *8*, e41028.

Choungo Nguekeng, P. B., Hendre, P., Tchoundjeu, Z., Kalousová, M., Tchanou Tchapda, A. V., Kyereh, D., & Lojka, B. (2021). The current state of knowledge of shea butter tree (*Vitellaria paradoxa* cf gaertner.) for nutritional value & tree improvement in west & central africa. *Forests*, *12*(12), 1740.

Daae, E., Feragen, K. B., Sitek, J. C., & von der Lippe, C. (2022). It's more than just lubrication of the skin: parents' experiences of caring for a child with ichthyosis. *Health Psychology & Behavioral Medicine*, *10*(1), 335-356.

Dagar, J. C., Sileshi, G. W., & Akinnifesi, F. K. (2020). Agroforestry to Enhance Livelihood Security in Africa: Research Trends & Emerging Challenges. *Agroforestry for Degraded Landscapes: Recent Advances & Emerging Challenges-Vol. 1*, 71-134.

Daudu, A. K., Oladipo, F. O., Olatinwo, L. K., Kareem, O. W., & Dolapo, T. A. (2019). Differences in Food Crop Diversification between Male & Female Smallholder Farmers in Kwara State, Nigeria. *Journal of Agricultural Extension*, *23*(4), 1-9.

Dimobe, K., Ouédraogo, A., Ouédraogo, K., Goetze, D., Stein, K., Schmidt, M., & Thiombiano, A. (2020). Climate change reduces the distribution area of the shea tree (*Vitellaria paradoxa* CF Gaertn.) in Burkina Faso. *Journal of Arid Environments*, *181*, 104237.

Ejotre, I., Reeder, D. M., Matuschewski, K., Kityo, R., & Schaer, J. (2022). Negative Perception of Bats, Exacerbated by the SARS-CoV-2 Pandemic, May Hinder Bat Conservation in Northern Uganda. *Sustainability*, *14*(24), 16924.

Elias, M. (2016). Gendered knowledge sharing & management of shea (*Vitellaria paradoxa*) in central-west Burkina Faso. In *Gender & Forests* (pp. 293-312). Routledge.

Etoamaihe, U. J., Dirioha, N. R., Oke, U. K., & Babalola, O. (2022). Development & performance evaluation of a motorized tumble barrel feed/food mixer. *Poljoprivredna tehnika*, *47*(4), 15-27.

Essouman, E. P. F., Dadem, G. C., Temgoua, L. F., & Simo, D. A. B. (2021). Origin, non-monetary benefits & perspectives of domestication of Non-Timber Forest Products in the Mifi Division of the West Region of Cameroon. *International Journal of Forest, Animal & Fisheries Research*, *5*(3).

Falola, A., Mukaila, R., Akanbi, S. U. O., Olohungbebe, S. A., & Oluwatobiloba, C. A. (2022). Agripreneurial drive among women shea butter processors in Kwara State, Nigeria: the motivating factors & efficiency.

Fikus, B., Dorochowicz, A., Surma, Z., Kijewski, J., Leciejewski, Z., Michalski, J., & Trębiński, R. (2022). Investigations of Middle-Caliber Anti-Aircraft Cannon Interior Ballistics including Heat Transfer Problem in Estimation of Critical Burst Length. *Processes*, *10*(3), 607.

Gary, S. P., Smith, C. W., Lee, M. A., Goldstein, M. L., & Forslund, D. W. (1984). Electromagnetic ion beam instabilities. *The Physics of fluids*, *27*(7), 1852-1862.

Gbabo, A., Andrew, N., & Gana, I. M. (2016). Development and testing of a centrifugal fertilizer applicator. *37th Annual conference and Annual General Meeting*.

Gemechu, F. G. (2020). Embracing nutritional qualities, biological activities & technological properties of coffee byproducts in functional food formulation. *Trends in food science & technology*, *104*, 235-261.

Hale, I., Ma, X., Melo, A. T., Padi, F. K., Hendre, P. S., Kingan, S. B., & Van Deynze, A. (2021). Genomic resources to guide improvement of the Shea tree. *Frontiers in Plant Science*, *12*, 720670.

Han, Y., Tai, X., You, W., Bai, Y., & Guo, L. (2022). Fabrication of ultrastable oil-in-water high internal phase gel emulsions stabilized solely by modified shea butter for 3D structuring. *Journal of Molecular Liquids*, *367*, 120495.

Houndonougbo, J. S. H., Kassa, B., Mensah, S., Salako, V. K., Glèlè Kakaï, R., & Assogbadjo, A. E. (2020). A global systematic review on conservation and domestication of Parkia biglobosa (Jacq.) R. Br. ex G. Don, an indigenous fruit tree species in Sub-Sahara African traditional parklands: current knowledge & future directions. *Genetic Resources & Crop Evolution*, *67*, 1051-1066.

Iddrisu, A. M., & Mills-Robertson, F. C. (2020). *Vitellaria paradoxa* fruit pulp bioethanol production potential: A review. *African Journal of Biochemistry Research*, *14*(2), 33-45.

Jasaw, G. S., Saito, O., & Takeuchi, K. (2018). Material flow analysis of shea butter production systems: Implications for Sustainability in Semi-arid Ghana. *Strategies for building resilience against climate & ecosystem changes in Sub-Saharan Africa*, 193-214.

Kadurumba, C. H. (2020). Development of a Ground-Breaking Multi-Juice Extraction Machine. *Nigeria Agricultural Journal*, *51*(3), 254-263.

Kamga, M. A. (2023). Unlocking Africa's land potential & addressing its problems through sustainable land management. *African Journal on Land Policy & Geospatial Sciences*, *6*(1), 209-2014.

Kelly, B. A., Poudyal, M., & Bouvet, J. M. (2019). Impact of land use & land use history on fruits production of *Vitellaria paradoxa* (Shea tree) according to agroclimatic zones in Mali (West Africa). *Current Botany*, *10*, 1-7.

Khadatkar, A., & Mathur, S. M. (2022). Design & development of an automatic vegetable transplanter using a novel rotating finger device with push-type mechanism for plug seedlings. *International Journal of Vegetable Science*, *28*(2), 121-131.

Khurmi, R. S., & Gupta, J. K. (2005). *A textbook of machine design*. S. Chand publishing.

Kolo, S. I., Dadi-Mamud, N. J., Aliyu-Paiko, M., & Jubril, B. (2022). Shea (*Vitellaria paradoxa*) Pulp Juice Production & Quality Evaluation via Proximate & Mineral Composition Analyses. *Journal of Applied Sciences & Environmental Management*, *26*(10), 1727-1731.

Koloche, I. M., Solomon, S., Adaigbe, V. C., Yahaya, S. A., Odufale, O. O., Garba, M. H., & Bello, O. G. (2023). Socio-economic Characteristics of German International Corporation (GIZ) Technology Intervention on Shea Nut Processors in Niger State, Nigeria. *Asian Journal of Agricultural Extension, Economics & Sociology*, *41*(1), 86-104.

Koloche, I. M., Solomon, S., Adaigbe, V. C., Yahaya, S. A., Odufale, O. O., & Garba, M. H. (2022). Adoption of German International Corporation (GIZ) technology intervention on shea nut processing in Niger State, Nigeria. *Journal of Agricultural Extension & Rural Development*, *14*(4), 190-197.

Mamatov, F., Mirzaev, B., Rustamova, N., Razzokov, T., & Hamroev, O. (2023). Kinematic mode of operation of potato harvester auger. In *E3S Web of Conferences* (Vol. 365, p. 04029). EDP Sciences.

Maanikuu, P. M. I., & Peker, K. (2017). Medicinal & nutritional benefits from the shea tree (*Vitellaria paradoxa*). *Journal of Biology Agriculture & Healthcare*, *7*(22), 51-57.

Masters, E. T. (2021). Traditional food plants of the upper Aswa River catchment of northern Uganda—a cultural crossroads. *Journal of Ethnobiology & Ethnomedicine*, *17*(1), 1-21.

Miazek, K., Beton, K., Śliwińska, A., & Brożek-Płuska, B. (2022). The Effect of β-Carotene, Tocopherols & Ascorbic Acid as Anti-Oxidant Molecules on Human & Animal in Vitro/In Vivo Studies: A Review of Research Design & Analytical Techniques Used. *Biomolecules, 12*(8), 1087.

Naangmenyele, Z., Banye, E. Z., Bekoe, E. M. O., Zakaria, I., & Amuah, E. E. Y. (2023). Fundamentals of shea butter production; input-output analyses & profit maximization in Northern Ghana. *Research in Globalization*, 100113.

Nair, P. R., Kumar, B. M., Nair, V. D., Nair, P. R., Kumar, B. M., & Nair, V. D. (2021). Silvopastoral Systems (SPS) in the Tropics & Subtropics. *An Introduction to Agroforestry: Four Decades of Scientific Developments*, 169-193.

Odoi, J. B., Odong, T. L., Okia, C. A., Okullo, J. L., Okao, M., Kabasindi, H., & Gwali, S. (2020). Variation in Seedling Germinationand Growth in Five Populations Ofvitellariaparadoxa CF Gaertn. subsp. Nilotica: A Threatenedusefulfruit Tree Species in Uganda.

Oduro Akrasi, R., Egyir, I. S., Wayo Seini, A., Awo, M., Okyere, E., & Barnor, K. (2021). Food Security in Northern Ghana: Does Income from Shea Based Livelihoods Matter?. *Forests, Trees & Livelihoods*, *30*(3), 169-185.

Ogunjirin, O. A., Ola, O., Farounbi, A. J., & Ogini, F. U. (2021). Development of Improved Coffee Bean Depulping Machine, *International Journal of Research in Agricultural Sciences* Volume 8, Issue 1, ISSN (Online): 2348 – 3997

Olaoye, J. O. (2011). Development of small scale equipment for depulping locust bean seeds. *International Journal of Engineering & Technology, 11*(06).

Pitigala, N., & Lopez-Calix, J. (2021). Trade policy options for export diversification: The case of Mali, Chad, Niger, & Guinea. *Journal of Infrastructure, Policy & Development*, *4*(2), 261-286.

Rotta, N. M., Curry, S., Han, J., Reconco, R., Spang, E., Ristenpart, W., & Donis-González, I. R. (2021). A comprehensive analysis of operations & mass flows in postharvest processing of washed coffee. *Resources, Conservation & Recycling*, *170*, 105554.

Saha, S., Hussain, A., Lee, J., Lee, E., & Lee, H. S. (2023). An integrated leachate bed reactor–anaerobic membrane bioreactor system (LBR-AnMBR) for food waste stabilization & biogas recovery. *Chemosphere*, *311*, 137054.

Sanchi, I. D., Alhassan, Y. J., & Sabo, A. Y. (2022). Examination of the Role of Extension Agents in Shea Butter Processing & Marketing in Zuru Agro-Ecological Zone of Kebbi State, Nigeria. *South Asian Research Journal of Agriculture and Fishery*, *4*(3), 52-59.

Seghieri, J. (2019). Shea tree (*Vitellaria paradoxa* Gaertn. f.): from local constraints to multi-scale improvement of economic, agronomic & environmental performance in an endemic Sudanian multipurpose agroforestry species. *Agroforestry Systems*, *93*(6), 2313-2330.

Shea, J. J. (2020). Prehistoric stone tools of Eastern Africa: a Guide. *Cambridge University Press.*

Sinaga, E., Iswahyudi, M., Setyowati, S., & Prasasty, V. D. (2021). Effect of supplementation of Rhodomyrtus tomentosa fruit juice in preventing hypercholesterolemia & atherosclerosis development in rats fed with high fat high cholesterol diet. *Biomedicine & Pharmacotherapy*, *142*, 111996.

Sobechukwu, M. C., Ogbonna, E. S., & Stanley, U. T. (2016). Conceptual Design & Computer Aided Static Analysis of Frame & Plates of a Continuous Process Breadfruit De-Pulping Machine. *American Journal of Mechanical Engineering & Automation*, *3*(3), 22-28.

Sodimu, A. I., Adamu, I., Baba, G. O., & Olaifa, R. K. (2022). Ethnobotany utilization of shea butter (*Vitellaria paradoxa* CF Gaertn) in two selected local government areas of Kaduna, Nigeria. *Journal of Research in Forestry, Wildlife & Environment*, *14*(3), 126-134.

Tom-Dery, D., Eller, F., Reisdorff, C., & Jensen, K. (2018). Shea (*Vitellaria paradoxa* CFGaertn.) at the crossroads: current knowledge & research gaps. *Agroforestry Systems*, *92*,1353-1371.

Tom-Dery, D., Jensen, K., & Reisdorff, C. (2019). Shea (*Vitellaria paradoxa* CF Gaertn.) seedlings recovery after fire: gas-exchange, growth & biomass partitioning assessment. *Forests, Trees & Livelihoods*, *28*(3), 214-220.

Ugwu-Dike, P., & Nambudiri, V. E. (2022). A review of ethnomedicinal uses of shea butter for dermatoses in sub-saharan africa. *Dermatologic Therapy*, *35*(3), e14786.

Vandebroek, I., & Picking, D. (2020). *Popular medicinal plants in Portland and Kingston, Jamaica* (pp. 89-94). Springer.

Wajim, J. (2020). Impacts of deforestation on socio-economic development & environment in Nigeria. *International Journal of Social Sciences & Humanities Invention*, *7*(03), 5852-5863.

Wardell, D. A., Elias, M., Zida, M., Tapsoba, A., Rousseau, K., Gautier, D., & Bama, T. (2021). Shea (*Vitellaria paradoxa* CF Gaertn.)–a peripheral empire commodity in French West Africa, 1894–1960. *International Forestry Review*, *23*(4), 511-533.

Wardell, D. A., Tapsoba, A., Lovett, P. N., Zida, M., Rousseau, K., Gautier, D., & Bama, T. (2021). Shea (*Vitellaria paradoxa* CF Gaertn.)–the emergence of global production networks in Burkina Faso, 1960–2021 1. *International Forestry Review*, *23*(4), 534-561.

Wilson, R. T. (2019). The Botany of Mungo Park's Travels in Africa, 1795-1806. *Asian Journal of Geographical Research*, *2*(1), 1-19.

Yeboah, J., Segbefia, M. A. D., Dadzie, A. M., Padi, F., Lowor, S. T., Agene, V. N. & Owusu-Ansah, B. (2020). Cutting Propagation of Shea (*Vitellaria paradoxa* CF Gaertn) Tree Using Shoot Types & Application of Auxin. *Journal of Agricultural Science*, *12*(12), 213.

APPENDIX A

Table 4.1: Effect of Speed on the Actual Capacity of the Machine

	Actual Capacity at three moisture level		
Speed (rpm)	15%	20%	25%
500	20.24	20.5	20.44
750	21.94	21.57	20.99
1000	22.5	22.4	22.75

Table 4.2: Effect of Speed on the Depulping Efficiency of the Machine

	Depulping Efficiency at three moisture level		
Speed (rpm)	15%	20%	25%
500	81	78.5	87.5
750	85	80	83
1000	87	83.5	88.5

Table 4.3: Effect of Speed on the Kernel Breakage of the Machine

	Kernel Breakage at three moisture level		
Speed (rpm)	15%	20%	25%
500	3.62	1.72	1.78
750	3.5	2.61	1.75
1000	3.655	2.82	1.73

Table 4.4: Effect of Speed on the Pulp Loss of the Machine

	Pulp Loss at three moisture level		
Speed (rpm)	15%	20%	25%
500	7.5	9.5	9.76
750	8	8.65	9.7
1000	8.7	8.7	9.55

Table 4.5: Effect of Feed Rate on the Actual Capacity of the Machine

	Actual Capacity at three moisture level		
Feed rate (kg/min)	15%	20%	25%
20	11.03	10.86	10.49
40	11.97	11.94	13.5
60	10.16	12.4	11.45

Table 4.6: Effect of Feed Rate on the Depulping Efficiency of the Machine

	Depulping Efficiency at three moisture level		
Feed rate	15%	20%	25%
20	81.25	85	87.5
40	83.5	87.5	76
60	87.5	88	89

Table 4.7: Effect of Feed Rate on the Kernel Breakage of the Machine

	Kernel Breakage at three moisture level		
Feed rate (kg/h)	15%	20%	25%
20	3.68	3.5	3.41
40	2.41	2.62	2.81
60	1.78	1.69	1.75

Table 4.8: Effect of Feed Rate on the Pulp Loss of the Machine

Pulp Loss at three moisture level			
Feed Rate	15%	20%	25%
20	8.025	8	7.65
40	8.7	8.65	8.75

60	9.76	9.5	9.7

Table 4.9: ANOVA for Depulping Efficiency

Response 1 De-pulping Efficiency

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	347.0443	9	38.56048	1.303795	0.3411	not significant
A-Speed	62.52459	1	62.52459	2.114062	0.1766	
B-Moisture	30.73287	1	30.73287	1.03913	0.3321	
C-Feed rate	49.4081	1	49.4081	1.670571	0.2252	
AB	25.68418	1	25.68418	0.868425	0.3733	
AC	76.82594	1	76.82594	2.597615	0.1381	
BC	18.95907	1	18.95907	0.641038	0.4419	
A^2	12.72099	1	12.72099	0.430118	0.5267	
B^2	78.78832	1	78.78832	2.663966	0.1337	
C^2	13.83343	1	13.83343	0.467732	0.5096	
Residual	295.7557	10	29.57557			
Lack of Fit	160.2557	5	32.05114	1.182699	0.4292	not significant
Pure Error	135.5	5	27.1			
Cor Total	642.8	19				

Table 4.10: ANOVA for Kernel Breakage

Response 2 Kernel Breage

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	10.69538	9	1.188376	32.99267	< 0.0001	significant
A-Speed	8.61E-05	1	8.61E-05	0.002392	0.9620	
B-Moisture	8.049788	1	8.049788	223.4849	**< 0.0001**	
C-Feed rate	0.00695	1	0.00695	0.192951	0.6698	
AB	0.002453	1	0.002453	0.068088	0.7994	
AC	0.004265	1	0.004265	0.118409	0.7379	
BC	0.034417	1	0.034417	0.955519	0.3514	
A^2	0.0003	1	0.0003	0.008341	0.9290	
B^2	0.007771	1	0.007771	0.215747	0.6522	
C^2	0.002894	1	0.002894	0.080357	0.7826	
Residual	0.360194	10	0.036019			
Lack of Fit	0.131044	5	0.026209	0.571869	0.7227	not significant
Pure Error	0.22915	5	0.04583			
Cor Total	11.05558	19				

Response 3 Actual Capacity

ANOVA for Response Surface Quadratic Model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	21.4093	9	2.378811	5.270316	**0.0079**	significant
A-Speed	11.81467	1	11.81467	26.17571	**0.0005**	
B-Moisture	0.02937	1	0.02937	0.06507	0.8038	
C-Feed rate	0.044292	1	0.044292	0.098129	0.7605	
AB	4.3E-06	1	4.3E-06	9.52E-06	0.9976	
AC	0.111218	1	0.111218	0.246406	0.6303	
BC	0.031292	1	0.031292	0.069327	0.7977	
A^2	9.35E-05	1	9.35E-05	0.000207	0.9888	
B^2	0.210016	1	0.210016	0.465297	0.5106	
C^2	1.651336	1	1.651336	3.658577	0.0848	
Residual	4.513602	10	0.45136			
Lack of Fit	4.446202	5	0.88924	65.96739	0.0001	significant
Pure Error	0.0674	5	0.01348			
Cor Total	25.9229	19				

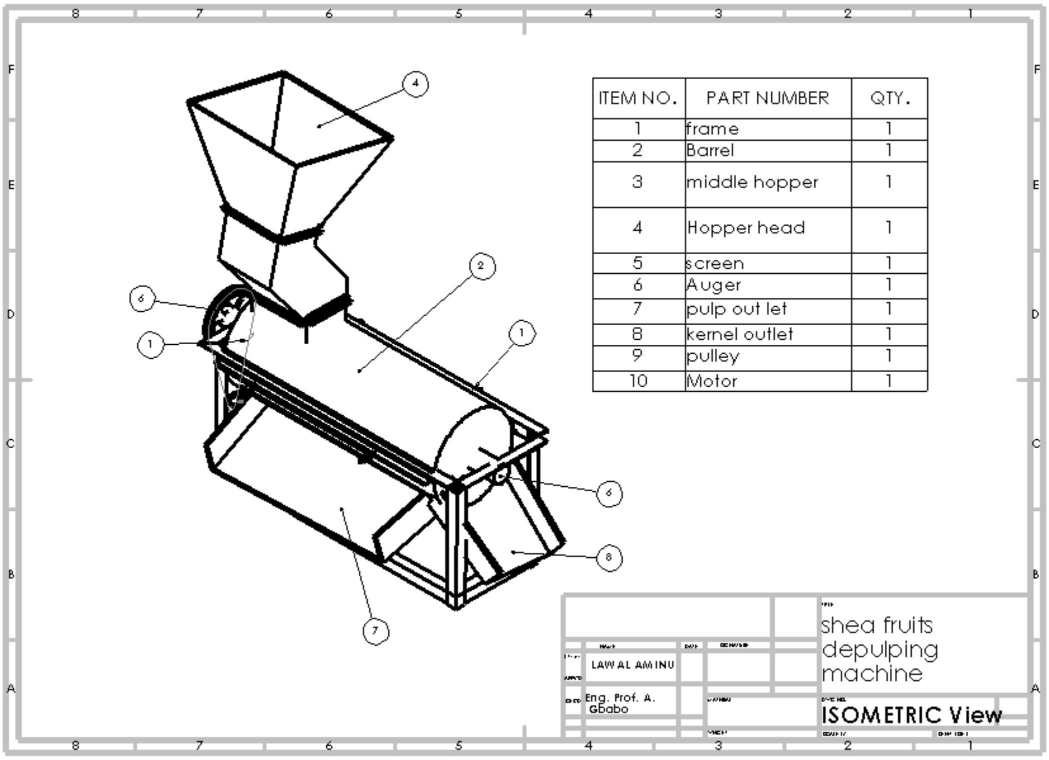
Response 4 Pulp retained

ANOVA for Response Surface Quadratic Model

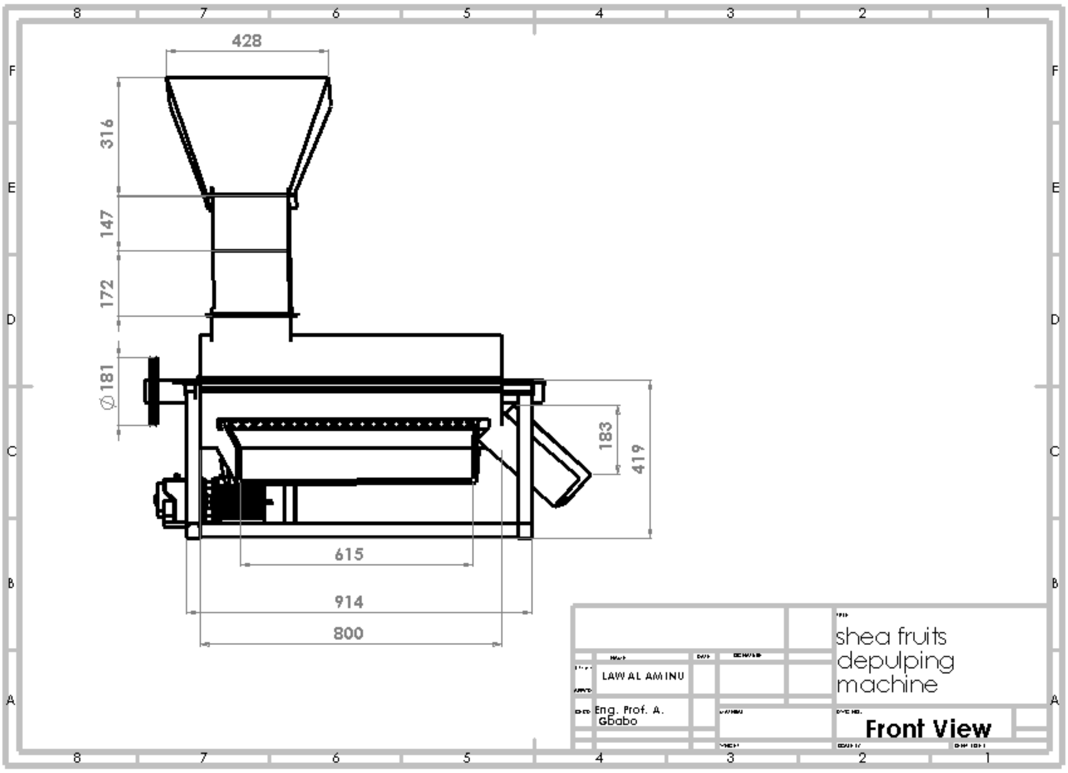
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob > F	
Model	4.991791	9	0.554643	1.18183	0.3966	not significant
A-Speed	1.093504	1	1.093504	2.33003	0.1579	
B-Moisture	2.397191	1	2.397191	5.107917	0.0474	
C-Feed rate	0.783126	1	0.783126	1.668679	0.2255	
AB	0.157852	1	0.157852	0.336349	0.5748	
AC	0.377474	1	0.377474	0.804319	0.3909	
BC	0.023235	1	0.023235	0.04951	0.8284	
A^2	0.525657	1	0.525657	1.120066	0.3148	
B^2	0.201613	1	0.201613	0.429595	0.5270	
C^2	0.373238	1	0.373238	0.795293	0.3935	
Residual	4.693089	10	0.469309			
Lack of Fit	0.440889	5	0.088178	0.103685	0.9868	not significant
Pure Error	4.2522	5	0.85044			
Cor Total	9.68488	19				

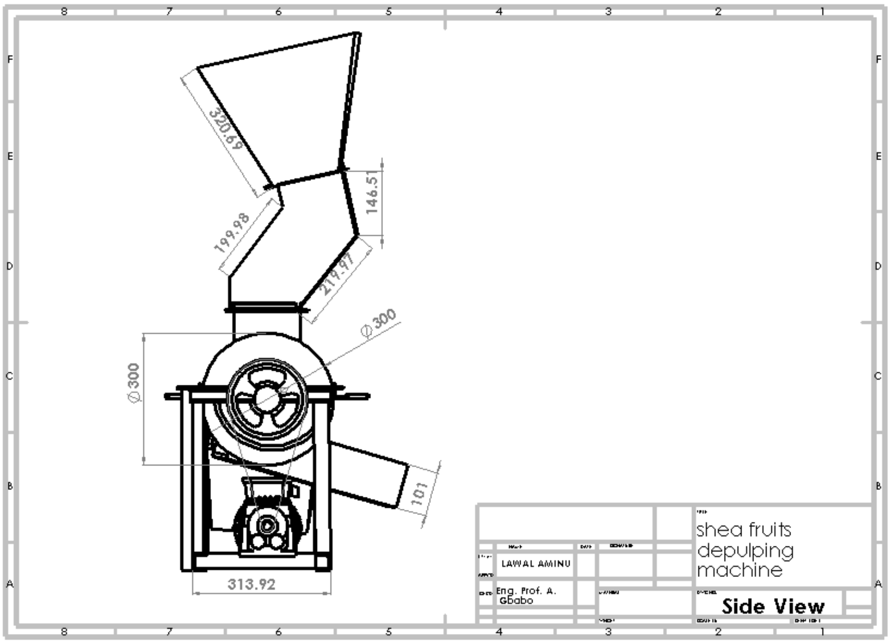
APPENDIX B



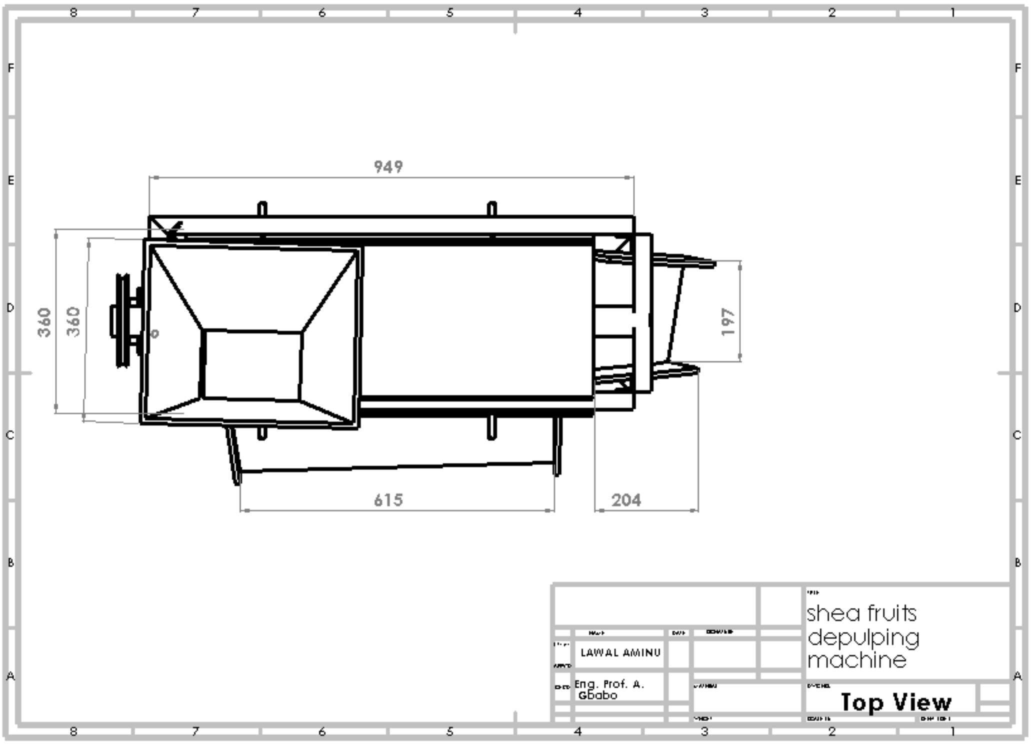
DETAIL VIEW OF THE MACHINE



FRONT VIEW OF THE MACHINE



SIDE VIEW OF THE MACHINE



TOP VIEW OF THE MACHINE

APPENDIX C

3.2 DESIGN CALCULATIONS

3.2.1 Theoretical capacity

The assumed weight of the machine is 1000kg of the shea fruits would be depulp in a day consisting of 8hr of work, therefore the theoretical capacity of the machine is 125kg/hr.

3.2.2 Determination of the diameter of the screw conveyor

The screw conveyor is a major component of the machine unit. It is acted upon by the weights of the pulley and screw thread. In operation, the screw conveyor conveys and squeezes the endothermal part of the shea nuts by bruise force. Therefore, in order to safeguard against bending and torsional stresses, the diameter of the shaft is determined from the equation (3.1) given by Khadatkar and Mathur (2022) as:

$$d_s^3 = \frac{16}{\pi\delta_o}\sqrt{(k_b m_{b)^2} + (k_t m_t)^2} \qquad (3.1)$$

Where:

d_s = diameter of screw auger (mm)

δ_o = allowable shear stress (55×10^6 N/m^2 for shaft without keyway)

k_b = combined shock and fatigue factor applied to bending moment

k_t = combined shock and fatigue factor applied to torsional moment

k_b = 1.5 and k_t = 1.0 (for load applied gradually)

m_b = maximum bending moment kNm

m_t = maximum torsional moment kNm

T = 60Nm π = 3.142 δ_0 = 55 x 106 N/m^2

K_b = 1.5

K_t = 1.0

m_b = 0.01998 kNm

m_t = 0.0247 kNm

Substituting the values above the into equation (3.1)

$$d_s^3 = \left\{\frac{16}{\pi \times 55 \times 10^6} \sqrt{(1.5 \times 0.01998)^2 + (1.0 \times 0.0247)^2}\right\}$$

$$ds = 20\,mm$$

3.2.3 Determination of the throughput rate

To effectively determine the sizes of the screw, the throughput capacity is important to ensure that the material pressure exerted on the screw is within design. The throughput flow rate is in equation (3.2) as given by (Ani *et al*., 2020) as;

$$\mathrm{Q} = \frac{\mathrm{m}}{\mathrm{t}} \qquad (3.2)$$

Where;

Q = throughput capacity (kg/s)

m = assumed mass of the shea fruit 125kg/hr

t= time taken (sec)

Substituting values into equation (3.2)

$$Q = \frac{125}{60 \times 60} \quad (3.2)$$

$$Q = 0.035 \text{kg/sec}$$

3.2.4 Determination of the volume flow rate

The volumetric flow rate is the volume conveyed by the screw per unit time. It is also an important parameter of screw design showing the amount of materials flowing through the working chamber of the machine at a time. It can be calculated using the equation (3.3) given by (Saha *et al.*, 2023)

$$V = \frac{Q}{\rho} \quad (3.3)$$

where

ρ is the density of the shea fruit (356.2 kg/m³) (Saha *et al.*, 2023)

V is the volumetric flow rate (m^3/s)

Q is the throughput capacity (kg/s)

Substituting the values into equation (3.3)

$$V = \frac{0.035}{356.2}$$

$$V = 9.8 \times 10^{-5} \text{m}^3/s$$

3.2.5 Determination of speed of screw auger

The quantity of the shea fruit depulped by the machine depend on the speed of the screw auger which determine the free flow of materials inside the barrel without sticking to the barrel walls and without causing too much breakage of the shea nut as shown in equation (3.4) Bereziuk *et al*. (2023).

$$C_{th} = \frac{\pi(D^2 \times S \times Q)}{4} \quad (3.4)$$

Making S subject of the formula;

$$S = \frac{4 \times C_{th}}{[\pi \times D^2 \times Q]} \quad (3.5)$$

Where;

C_{th}=Theoretical capacity (kg/hr)

D= the diameter of the screw (mm)

S = speed of the screw auger (rpm)

Q = the Throughput rate of the materials (kg/s)

Substituting values into the equation 3.4;

$$S = \frac{4 \times 125}{[3.142 \times 20^2 \times 0.035]}$$

$$S = 11.368\text{rpm}$$

3.2.6 Determination of pressing area and pressure developed by the auger

The auger pressure and pressing area are designed to provide efficient bruise forces required to remove the pulp parts of the shea nuts. The pressing area and the pressure developed by the auger were determined from equations (3.5) and (3.6) respectively given by Bereziuk *et al*. (2023) as:

$$A_p = \pi D_m nh \quad (3.6)$$

Where:

A_p = Pressing area (mm^2)

h = Screw depth at the maximum pressure (discharged end), mm;

n = number of threads

D_m = diameter of the shaft (mm)

D_m = 20 mm

h =3 mm

π = 3.142

n = 5

Substituting values into the equation 3.5;

$A_p = 3.142 \times 20 \times 5 \times 3$

$A_p = 942.5\ mm^2$

Pressure developed by the auger

$$P_r = \frac{W_f}{A_P} \tag{3.7}$$

Where:

P_r = pressure developed by the auger, (N/mm^2)

A_p = Pressing area (mm^2)

W_f = Force acting on the screw auger (N)

To determine force acting on the screw auger, assuming a torque of 540 Nm, and using the same values for the diameter of the auger (20 mm) and the coefficient of friction (0.3). The force acting on the screw auger can be calculated using the formula given in equation (3.8) as stated by Bulgakov *et al* (2022)

$$F = \frac{T_q}{R \times C_f} \tag{3.8}$$

Where:

F = Force (N)

R = Radius is half of the diameter, or 10 mm = 0.01m

T_q = Torque (N)

C_f = Coefficient of friction

Substituting the values into the equation 3.7;

$$F = \frac{540}{0.01 \times 0.3} = 18000 \text{ N}$$

F = 18 KN

A_p = 942.5 mm^2

W_f = 18KN

Substituting values into the equation 3.8;

$$P_r = \frac{18}{942.5}$$

$$P_r = 0.0191 \text{ N/mm}^2$$

3.2.7 Determination of pressure develop by auger on the barrel

The pressure developed by the auger on the barrel can be determined by considering the forces acting on the material being bruised through the barrel. The pressure developed on the barrel guides on the appropriate materials for the barrel selection. The pressure to be withstood by the barrel was determined from equation (3.9) and (3.10) (Kadurumba, 2020):

$$P_b = \frac{2t\delta_a}{Di} \qquad (3.9)$$

Where:

P_b = pressure on the barrel (Nm^2)

t = thickness of the barrel (mm)

D_i = the inside diameter of the barrel (mm)

δ_a= allowable stress, ($\delta_a = 0.27\delta_o$) (Nm^2)

Allowable stress for barrel can be calculated using equation;

$$\delta_a = (\delta_a = 0.27\delta_o) \qquad (3.10)$$

Where:

δ_a= allowable stress, (Nm^2)

δ_o= the yield stress for mild steel (Nm^2)

$\delta_a = 0.27\delta_0$

$\delta_0 = 200\ N/m^2$

Substituting the values into equation (3.9);

$\delta_a = 0.27 \times 200$

$\delta_a = 54\ N/m^2$

Di = 44 mm

$t = 10$ mm

$\delta_a = 54$ N/m^2

Substituting the values into the equation (3.8);

$$= \frac{2 \times 10 \times 54}{44}$$

$P_b = 24.55$ N/m^2

3.2.8 Determination of the screw pitch

The screw pitch serves the purpose of providing enough clearance and assisting in the cutting or shearing of the material that is conveyed between the screw and the wall of the barrel. The pitch of the screw can be calculated using the following formula given in euation (3.11) (Kadurumba, 2020):

$$P = \pi \times \frac{D}{N_t} \tag{3.11}$$

Where:

P = pitch of the screw (mm)

D = screw diameter (mm)

N_t = number of threads

$D = 20$ mm

$N_t = 3$

Assuming a triple-flight screw ($N_t = 3$), the pitch of the screw can be calculated as:

Substituting values into the equation 3.10;

$$p = \pi \times \frac{20}{3}$$

$$P = 20.95 \text{ mm}$$

3.2.9 Determination of length of the barrel

The length of the barrel is a crucial factor that impacts the extrusion process. It is recommended that the diameter of the barrel be slightly greater than that of the screw to enable smooth material flow. The barrel length can be calculated using the formula given equation (3.12) by Fikus *et al.* (2022) as;

$$L_b = Ls + 4 \times D \tag{3.12}$$

Where:

L_b = barrel length (mm)

L_s = screw length (mm)

D = screw diameter (mm)

Assuming a screw length of 300 mm,

Substituting values into the equation 3.11;

$$L_b = 300 + 4 \times 20$$

$$L_b = 380 \text{ mm}$$

3.2.10 Determination of the power requirement for depulping

The design for motor output power enables appropriate selection of a motor with enough power to start and run the machine at full load. The power requirement of the machine for depulping of the kernel out of the shea nuts and power required to drive all other units, can be calculated using the equation (3.13) given by Bulgakov *et al.*, 2022) as:

$$P_e = 4.5 \times Q_{vc} \times l_s \times \rho \times g \times F \tag{3.13}$$

Where:

P_e = power requirement for depulping

Q_{vc} = volumetric capacity

l_s = length of screw shaft

ρ = density of the material

g = acceleration due to gravity

F = the material factor.

$Q_{vc} = 0.035 m^3/s$

l_s = 300mm

ρ = 356.2kg/m^3

g = 9.81 m/s^2

F = 0.5 (N)

Substituting values into the equation 3.12;

$$P_e = 4.5 \times 0.035 \times 0.3 \times 356.2 \times 9.81 \times 0.5$$

P_e= 82.55 w

P_e = 0.1 hp

3.2.11 The drive system

V-belt and pulley arrangement were adopted in this project to transmit power from the electric motor to the shaft of the depulping unit. The main reasons for adopting the v-belt drive are its absorbed shocks thereby mitigating the effect of vibratory forces (Olaoye, 2011).

i. Determination of the machine pulley diameter

The pulley provides the simple way to transfer the power from one shaft to another, the pulley diameter for depulping screw is computed using the formula given in equation (3.14 and 3.15) as cited (Olaoye, 2011)

$$N_1D_1 = N_2D_2 \tag{3.14}$$

Making D_2 the subject of formula;

$$D_2 = \frac{N_1D_1}{N_2} \tag{3.15}$$

Where:

D_1 = Diameter of electric motor pulley, 80mm

N_1 = Speed of motor, 1500rpm

D_2 = Diameter of depulping Screw pulley, mm

N_2 = Assumed Working Speed of depulping screw unit, 1000rpm

Substituting values into the equation 3.14;

$$D_2 = \frac{1500 \times 80}{1000}$$

$$D_2 = 120\ mm$$

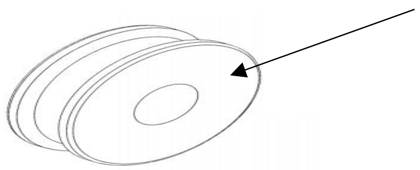


Figure 3.1: Pulley

i. Belt Length

Well calculated belt length is necessary to avoid reduced tension of the belt and ensure efficient power transfer to the depulping unit. The Belt length for the depulper drive can be determined using the formula as expressed equation (3.16) Etoamaihe *et al*. (2022);

$$X = 2C + 1.57(D_1 + D_2) + \frac{(D_1 - D_2)^2}{4C} \quad (3.16)$$

Where:

X = belt length, m

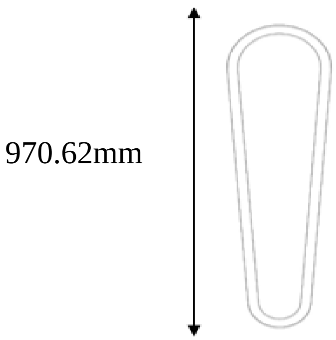
C = Center distance between pulleys, 350mm

D_1 = Pitch diameter of driver pulley, 50mm

D_2 = Pitch diameter of driven pulley, 120m

Substituting values into the equation 3.15;

$$X = 2 \times 350 + 1.57(50 + 120) + \frac{(50 - 120)^2}{4 \times 350}$$



$$X = 970.62\ mm$$

Figure: 3.2 Belt

ii. Belt Tension

The belt tension is required to provide proper contact between belt and pulley, it measured in newton (N). given in equation (3.17) Khadatkar and Mathur (2022) as

$$T = \frac{W \times g \times (\mu \times \tan\theta)}{2 \times \cos\theta} \tag{3.17}$$

Where:

T = Tension (N)

W_e= load that can be conveyed by the screw (kW)

g = acceleration due to gravity= 9.8m/s^2

θ = angle of contact= 15^o

μ = Assuming coefficient of friction between belt and pulley = 0.5

Substituting values into the equation 3.16;

$$T = \frac{14 \times 9.8 \times (0.5 \times tan15)}{2 \times cos15}$$

$$T = 9.51N$$

3.2.13 Selection of bearing

The basis for the selection bearing size according to Gary *et al.*, (1984) are the radial loading (W_r), thrust or axial load (W_a), the speed (N), required life (L_R) and the vibration condition. The dynamic radial equivalent load for bearing on the depulping shaft is expressed in equation (3.18) Khurmi and Gupta, (2005) as;

$$W_E = X.V\ W_r + YW_a \tag{3.18}$$

Where:

$$W_r = Radial\ Load\ (KN)$$

W_a = Axial load or Thrust (N)

To find the radial load;

$$W_r(Radial\ Load) = \frac{P}{2\pi Nr} \quad (3.19)$$

$$W_r = \frac{20.68}{2 \times \pi \times 800 \times 0.020}$$

$$W_r = 0.137\ KN$$

W_a (Axial load or Thrust) = Weight of shaft + Load on shaft

$$W_a = \left(\frac{7800 \times 3.142 \times 0.03^2 \times 0.55 \times 9.81}{4}\right) + 71.4 + 6.33$$

$$W_a = 29.75 + 71.4 + 6.33 = 107.5N$$

The values of X and Y are obtained from the standard table using the ratio $\frac{W_a}{W_r} = \frac{107.5}{0.137} = 29.8$

This means that the bearing should be selected for W_E 117.29 N. A6305 ball bearing dynamic load rating (C) of 16,600 N, bore diameter of 25 mm, outer diameter 62 mm and width of 17 mm was chosen for this design.

3.2.14 Determination of height of the feed hoppers

The feed hoppers are trapezoidal in shape in order to accommodate enough nuts and gradually introduce portions of the nuts by gravity into the depulping compartments.

Supposing the hopper is to hold 30kg of shea nuts and the bulk density of shea fruit is 356.2Kg/m^3.

The height of hopper can be calculated using the expression below:

Bulk density = 356.2Kg/m^3

Mass of the shea fruit = 30Kg

$$V = \frac{m}{\rho} \qquad (3.20)$$

V = volume of hopper, D = height of hopper, C = width of upper end, A = hopper length of hopper, B = lower length

E = 400 mm

F = 200 mm

G = 300 mm

H =?

The hopper is assumed to have a volumetric capacity of 60.0litres.

$$V = \frac{30}{356.2}$$

$$V = 0.08422m^3$$

To calculate the height of the hopper;

The average height of the hopper:

Calculate the height of a trapezoidal hopper which is assumed to hold 30kg of shea fruit, length and width of the hopper is 300mm and 200mm respectively,

$$\mathrm{V} = \left(\frac{1}{3}\right)\mathrm{h}(\mathrm{a}^2 + \mathrm{ab} + \mathrm{b}^2) \qquad (3.21)$$

$$0.060 = \frac{1}{3} \times \mathrm{h} \times (0.4^2 + 0.4 \times 0.2 + 0.2^2)$$

$$h = \frac{0.060 \times 3}{0.28}$$

$$h = 643mm$$

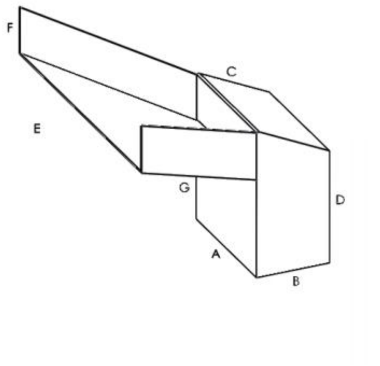


Figure 3.3: Hopper