DESIGN AND FABRICATION OF A SOLAR POWERED YAM POUNDING MACHINE

BY

URHOGHIDE OSARENOMASE GABRIELLA

ENG2006473

A PROJECT SUBMITTED TO THE DEPARTMENT OF PRODUCTION ENGININEERING DEPARTMENT, FACULTY OF ENGINEERING UNIVERSITY OF BENIN

BENIN CITY.

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

AWARD OF BACHELOR OF ENGINEERING (B.ENG) IN

PRODUCTION ENGINEERING

SUPERVISED BY: ENGR DR.(MRS) A. EKIUGBO

NOVEMBER, 2025

CERTIFICATION

I hereby certify that this project work **DESIGN AND FABRICATION OF A SOLAR POWERED YAM POUNDING MACHINE** was carried out by Urhoghide Osarenomase Gabriella with matriculation number ENG2006473 in the department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria, in partial fulfillment of the requirements for the award of Bachelor of Engineering (B. Eng).

……………………………..   ………………………

Engr. Dr. A Ekiugbo   Date

(Project Supervisor)

………………………………   ……………………………

Engr. Dr. E. M. Etuk   Date

(Project Coordinator)

…..…………………………..   …………………………..

Engr. Prof. P Amiolemhen   Date

Head of Department

Production Engineering Department

DEDICATION

This Project is dedicated to God Almighty for all His protection, love, and His overwhelming grace and mercy upon my life, and to my amazing family and friends for their unwavering support

ACKNOWLEDGEMENT

My everlasting appreciation is to God Almighty for His continuous protection, love, care grace and mercies upon my life and for His strength that has kept me thus far.

I am very grateful to my supervisor Engr. Dr. (Mrs) Afoke Ekiugbo for her patience, love, support, supervision and guidance at all stages of this project.

My sincere appreciation goes to my loving parents Hon and Mrs Osazee Urhoghide for their continuous prayers, having faith in me, understanding and support all through the period of my stay in school.

I am also grateful to my course adviser Engr. Dr. Idada Osayi for is constant advice and guidance as one of his students.

I am most thankful to my amazing siblings Aisosa Osa-Iguma, Aizeyosabor, Osazuwamen, Aiyevbosa Urhoghide, for their constant prayers, care, motivation and support towards me and to Zion my amazing nephew for bringing so much joy to me.

I also want to appreciate my friends, church members and course mates for being part of my University of Benin Journey.

ABSTRACT

This project presents the design, development, and testing of a solar-powered yam pounding machine, aimed at reducing manual labor and promoting sustainable energy utilization in traditional yam processing. The machine combines a solar photovoltaic (PV) system with an electric motor to power a mechanical pounding mechanism, efficiently processing yams into a smooth, consistent paste. The solar-powered system ensures energy efficiency, reduces operational costs, and minimizes environmental impact compared to conventional fuel-based or electric grid-dependent systems. The design incorporates user-friendly features and adjustable settings to accommodate varying yam quantities and desired paste consistencies. This innovation addresses the challenges faced by small-scale yam processors and rural communities, enhancing productivity while promoting eco-friendly practices in food processing. The machine's performance was evaluated based on efficiency, output quality, and energy consumption, demonstrating its potential to transform yam processing and contribute to sustainable agricultural practices.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Yam is a staple food in many parts of the world, particularly in West Africa. However, the Processing of yam, especially pounding, is a labour-intensive and time-consuming task. Traditionally, yam pounding is done manually using a mortar and pestle, which requires significant physical effort and can lead to fatigue.

A pounder is a machine or device that applies a torque or reciprocating force to a solid piece to change its shape from a solid to a semi-solid or paste. There are two types of blows: rotational (torque) blows and striking (reciprocating) blows. The mortar and pestle pounding type is attributed to the reciprocating mode.

A **Solar – Powered** yam pounding machine is a mechanized machine or device just like the electric pounder, but uses solar energy to pound cooked yam into a smooth, dough-like consistency.

In the rotary pounding method, boiled yam is shredded through a pulley and shaft connected to a knife using the rotational force (torque) generated by the bowl. The construction of this machine and some existing twine tampers is based on this principle. Mash yam (Pounded yam) is a smooth dough made from mashed yam and is often eaten with different soups. (e.g, ogbono, egusi, banga, black soup). This is a very popular African dish, especially in the Middle Belt region, East and South of Nigeria. It is a highly respected dish in these parts of the country. For example, offering a visitor to Edo land, Nigeria, a dish of pounded yams and Egusi soup is considered a great act of hospitality. Yams are consumed in different ways in Nigeria besides pounding them. It can be boiled, fried, roasted or eaten as porridge.

Different ethnic groups in Nigeria have their own yam processing methods. The Yoruba process yams into powder (dehydrated yam flour) using sun drying or commercial dryers. Grinding yam has been practiced for a very long time, but it is very labour-intensive because it requires energy to create a smooth texture. Traditionally, pounded yam is made by boiling yam in a pot and then cooking. Place it in a mortar and manually pound and beat with a pestle to create a smooth, textured dough. Until a few years ago, the only way to pound yam was to use a mortar and pestle. The sound of pounding yams by hand can be unpleasant in homes or homes with multiple families. In addition to the frequent accidents during beating, it is also unhygienic as sweat drips into the yam during beating.

The advancement of solar-pounding machinery has revolutionized the manual pounding process by reducing human effort and saving energy. Solar-powered yam pounding machines have been specifically designed and built to simplify the preparation of pounded yam, eliminating the difficulties associated with the traditional mortar and pestle method. Numerous machines have been created by both local and foreign companies to enhance the pounding process, However, the foreign machines are not easily accessible due to their high cost.

Solar-Powered Yam pounding machines tend to be expensive primarily due to the costs associated with solar batteries, inverters, electric motors, structural materials, and machine components. The structural materials commonly used includes solar panel system, battery, stainless steel, aluminium, or plastic. The pounding bowl is a crucial component, and local manufacturers often utilize stainless steel pots readily available in the market. Alternatively, some employ cast aluminium pots. The use of plastic is uncommon because the production process requires a specialized mould, which significantly increases the cost

Traditionally, pounded yam was prepared using wooden mortars and pestles. Therefore, it might seem logical for the pounding bowls and other structural parts of a yam pounder to be made of wood, considering its easy availability and relatively low cost.

Yam belongs to the class of carbohydrate type of food and has been one of the oldest food recipe It has been a major food crop in many African countries such as Ghana, Ethiopia, Benin Republic and Nigeria in particular. Nigeria is the world's largest producer of yams, accounting for 70-76 percent of the world production. According to the Food and Agriculture Organization report, in 1985, Nigeria produced 18.3 million tons of yam from 1.5million hectares, representing 73.8 percent of total yam production in Africa. According to 2008 figures, yam production in Nigeria has doubled since 1985, with Nigeria producing 35.017 million metric tons with value equivalent of US$5.654 billion *(Wikipedia)*. Yam being one of the most sumptuous meals can be prepared in diverse ways. While the Yoruba tribe may prefer it dried, milled and then made into a slightly solid paste called "Amala" the Igbos would prefer cutting the tuber into smaller blocks or bits, boiled and eaten in other to avoid the tedious nature of pounding the boiled yam which results to bond formation like the Nigeria locally prepared *fufu* (Akissoe et al, 2003).

Pounded yam is a kind of food liked by most Nigerians, who want to eat yam in its pounded processed form. However, due to much energy, time and healthy process involved in getting the required texture, makes it difficult for most people to get it included as part of their meal menu in some families and this has limited the consumption rate of pounded yam. Yam still has remained as one of the most highly regarded food products in West Africa and particularly Nigeria as virtually all ethnic groups in the country feed on yam hence its close integration into socio-cultural, economic and religious aspect of life such as marriage where some tubers of yam are presented to the bride family in accordance to the customs of the people (Odior et al, 2012). Traditionally, pounded yam is made by boiling yams in a pot, and once cooked; it is placed in a mortar and pounded or beaten into smooth textured dough with a three- five-foot-tall pestle. This traditional pounding process is usually very tedious and laborious. Manual pounding of yam has been linked to muscular health problems arising from the tedious nature of the pounding process. The manual preparation of yam to pounded yam is highly time consuming especially when processing a large bulk of yam. Domestic disturbance with the use of mortar and pestle has not only be linked to the pounding action of yam, but it has also been associated with posing of danger to the structural integrity of buildings due to the impact force usually associated with the pestle vigorously dropping vertically on the mortar during pounding.

These setbacks associated with manual yam pounding has been greatly mitigated with the development of yam pounding machine. Various yam pounding machines which utilizes electro-mechanical power to process yam faster and more efficiently with little or no associated human effort have been developed over the years. However, contending issues with the mechanized yam pounding machine include the energy utilization which borders on electrical energy consumption and or unavailability which makes the pupation pounded yam costly or inaccessible to prospective

Increasing electrical tariff has made operation of electrical household items quite daunting and even in the absence of such energy, the consume or user of such machine becomes stranded and unable to use such machine. Consumers of pounded may find it difficult to process and eat the food as at when desired in the absence of electrical power from the mains supply. This setback has necessitated the need to incorporate solar powered energy devices to modern day yam pounding devices. The background of this study is hinged on the need to develop alternative powered yam pounding machine which can be utilized at most times, with less human input and cost by Nigerian families, newly wedded couples, bachelors/spinsters who find pounded yam as a sumptuous meal.

1.2 STATEMENT OF THE PROBLEM

In modern day, various mechanized yam pounders have been developed as a significant substitute to the manual processing of the food. However, many of these mechanical yam ponders rely significantly on mains electricity supply which can be costly and or unavailable to prospective consumers of pounded who may desire the food at a specific time. Against the backdrop of such setback, there is the need to develop yam pounding machines which can utilize solar power energy as a form of renewable energy that can be harnessed cheaply with storage ability to make yam pounding experience more convenient to consumers of the food.

1.3 AIM AND OBJECTIVES

The aim of the study is to design and fabricate a solar powered yam ponding machine suitable for use in rural and urban locations in Nigeria.

The objectives of the study include the followings:

i. To design and fabricate an electrical yam pounding machine that can be used to mechanically process cooked yam to pounded yam.

ii. To incorporate solar power facilities to the yam pounder to enhance its use at various times and in the absence of mains electricity supply.

1.4 SCOPE OF STUDY

The scope of the present research is hinged on yam (discorea spp.) pounding mechanization through the design of a solar powered yam pounding machine that can pound a variety of yams found in Nigeria and at various times even in the absence of mains electricity supply. This doesn't include other forms of tubers other than yam that is popularly used for making the pounded dough. The research will depend on experiments and reviews of previous literature works in a bid to achieve its aim and objectives. The proof of concept will be a small scale prototype which can be suited for small scale food processing in rural and urban places.

1.5 SIGNIFICANCE OF STUDY

The present study therefore will be significant in developing improved yam pounding device with the introduction of solar energy which can make the food to be processed and available at any time and at the desire of the consumer when and where there is no mains electricity. The development of an improved yam pounding machine will be significant in creating jobs and money for would be food vendors who can utilize such machine for commercial production of pounded yam in restaurants and hotels as well as in social occasions such as weddings, traditional rites, in rural and urban communities.

The use of mechanized solar powered form of yam pounding will reduce reliance in and cost of mains electricity in the food preparation pounded yam.

Commercial production of pounded yam through the use of a solar powered yam pounder will aid food export form place to place due to timely preparation and onward transfer before the food exceeds its shelf life.

1.6 ECONOMIC IMPORTANCE OF THE PROJECT

Majority of the materials or parts used for the fabrication of the Yam pounding machine are locally sourced hence any of these parts can easily be replaced in case of failure.

CHAPTER TWO

LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND OF POUNDED YAM AND THE SOLAR POWERED YAM POUNDING MACHINE

Pounded yam is low in fat and calories, and is a good dietary requirement for weight loss. Pounded yam is made from yam (discorea spp.) which is an essential staple food in West Africa (Ekwu et al., 2005). It is cultivated in Africa, the Americas, the Caribbean, the South Pacific and Asia on an annual and perennial basis. It is native to Western Africa (IITA, 2018). The word yam comes from Portuguese or Spanish name, which both ultimately derives from the word nyam, meaning "to sample" or "taste". In some African languages it can also mean "to eat" for example; yamyam and nyama in Hausa (Adegunwa, et al., 2011). Yam shown in Figure 2.1 is described as a perennial herbaceous crop comprising of different species such as the white yam (Dioscorea.rotundata), yellow yam (Dioscoreacayenensis), water yam (Dioscoreaalata) and trifoliate yam (Dioscorea. dumetorum) (Amusaet al., 2003). The fruit of yam consists of a membranaceous, three-wing capsule.

Figure 2.1 Yam Tuber

The yam family is mostly of the weak-stemmed vines with large, underground food storage organs-tuber-rhizomes. Nigeria generates 71 percent of the 94 percent of West African yam production, making a total of over 37 million tons (IITAA) (2018). Yam tubers are nutritionally made up of about 21% dietary fiber and are rich in carbohydrates, vitamin C and essential minerals. The physiological characteristics of yam was reported by Thomas et al (2017) who gave some physiological characteristics of a typical yam tuber as that with an ovoid shape, with average weight of 0.62-1.25kg, length of 210-270mm, diameter of 160-206mm and a dry texture. Pounded yam is a viscous sticky-dough and starchy food made from yam (discorea spp.) tubers. It is a glutinous dough made by peeling, boiling, pounding and kneading yam tubers. It is the dish of choice served to honored guests during festivals, weddings and various traditional ceremonies in many places in Africa (Otegbayo et al., 2005). Pounded yam is made from the application of force on cooked yam which masticates the cooked yam lumps to a thick marched consistency of dough. (Oluwamukomi and Adeyemi, 2015). Pounded yam is a Nigerian swallow food native to the Yoruba, Igbo, Tiv and Ebira and the Okun ethnic groups. Osinkolu (2019) and it is a known staple food in Yoruba culture and it is eaten all over Nigeria and other parts of Africa, Europe, and the Americas. (Raji and Oriola, 2007). Pounded yam shown in Figure 2.1 is a food with nutrients and health benefits. It is a good source of complex carbohydrates, which are essential for energy production.

Figure 2.2 Pounded yam

2.2 Pounded yam making process

The pounding process is one of the phases of the entire process of conversion of raw yam to the consumable thick sticky starchy dough. (Enahoro, 2025). The entire process of pounded yam making involves peeling of the yam tuber, cutting it into smaller sized pieces, washing the pieces and boiling them in a pot with the application of heat. The boiled and cooked yam is thereafter transferred into a pounding mechanism which could be a mortar or a mechanical device such as a yam pounding machine where the pounding process is initiated. The operational phases in making of pounded yam is graphically shown in the Figure 2.2.

Figure 2.3 the yam pounding process stages.

Pounded yam preparation can be done by the conventional or traditional methods and the mechanized methods.

2.2.1 Traditional yam pounding method.

The traditional yam pounding involves the use of human effort in the pounding of cooked yam to the viscous dough. The cooked yam is put in a mortar and is hit continuously with a pestle (shown in Figure 2.3) by abled men and or women who ensure the cooked sliced yams are masticated by the pestle hitting and turning action until it becomes a viscous dough. The mortar is a hard wooden deep hollow structure blinded about 100 cm in length 4cm in diameter at the narrow hand held stem and about 8 to 10cm diameter at its hammer head (Emetiri, 2025).

Figure 2.4 Traditional mortar and pestle action of yam.

Major setbacks of the traditional yam pounding methods include the followings;

i. The traditional yam pounding process is cumbersome requiring excessive human effort which often result to undue fatigue.

ii. It is froth with unhygienic activities which include sweat and external particles drops into the mortar during pounding.

iii. The cooking of yam as different activity before put into the mortar may be subject humans to risk and consumes productive time unnecessarily.

iv. Pounded yam made from the traditional can be froth with unwanted yam lumps which causes the pounded yam to have a rough texture to the hand and mouth.

2.2.2 Mechanized pounding

Mechanized yam pounding involves the use of machine to prepare pounded yam. It enables a total or partial removal the human effort involved in the traditional method. Pounding machines have common components such as; motor, frame, pot, pulleys, bearings, shaft, beaters and power control. A typical yam pounding machine is shown in Figure 2.4.

Figure 2.5 Motorized yam pounding machine.

2.3 Renewable Energy use in Yam Pounding Machine

The growing need for cheap and cleaner energies has necessitated the need to explore renewable sources through a systematic deployment of energy sources in single or multiple units that can maximize usage, reduce cost and eradicate environmental damage. . A lot of domestic and industrial activities being executed by man and machines utilize one form of energy or the other, however; the usage and amount depends on availability of the energy, amongst other factors. The developed nations today have put much effort into the discovering, production and utilization of a mix of energy sources, while the developing countries are yet to efficiently explore their limited sources of energy, or even explore new or other alternative energy sources. (Tere, 2022). In these respect, consumers, businesses and other energy dependent components have fallen short of adequate or required energy requirements. In Nigeria, like many other parts of the world, various energy sources are being explored amongst which are hydro energy, tidal energy, nuclear energy, solar energy, wind energy, etc., but except for the developed nations, it is still on the low to find many domestic and industrial facilities within many localities with a full-fledged deployment of these renewable energies. Various factors have contributed to the need for renewable energies development in Nigeria and around the world some of which include the followings; (RETIP, 2017)

i. Reduction and or elimination of fossil fuel pollution.
ii. Need to deploy cleaner energies
iii. The need for alternative sources to reduce reliance on fossil fuel energy sources.
iv. Extend electricity reach to remote areas where conventional power grids are costly or impractical to deploy.
v. Reduction in cost of energy production and utilization.

As a means of making pounded yam making process easily and cheaply available at virtually all times without relying so much on grid electricity supply, the present study is poised on incorporating solar powered systems to yam pounding machine. Solar energy is a radiant light and heat from the sun which is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, concentrated solar power (CSP), concentrator photovoltaics (CPV), solar architecture and artificial photosynthesis. The global solar energy share is shown in Table 2.1.

Table 2.1 Solar Energy global share. Source; Reuters, (2021)

Global comparativeness	Share	Date effective
Global electricity power generation capacity	849.5 GW	2021

Global electricity power generation capacity annual growth rate	26%	2012-2021
Share of global electricity generation	2%	2018
Leveled cost per megawatt hour	Utility-scale photovoltaics: USD 38.343	2019
Primary technologies	Photovoltaics, concentrated solar power, solar thermal collector	
Other energy applications	Water heating; heating, ventilation, and air conditioning (HVAC); cooking; process heat; water treatment	

This is energy from the sun. it involves the collection of sun rays using photovoltaic Figures made from silicon which then transform the solar energy into electric current which is passed through cables to an inverter for onward conversion into alternating current (AC) as maybe desired. Batteries can also be incorporated to store the electric energy during peak hours for later utilization. The various components of solar energy system set up include the followings;

a. Photovoltaic cells; are made up of special materials called semiconductors such as silicon, which is most commonly used. Basically, when light strikes the photovoltaic cell, a certain portion of it is absorbed within the semiconductor material. The absorbed energy knocks electrons loose, allowing them to flow freely (Oji et al 2012). The cells produce low voltage, consequently they are combined to form modules and the modules combined to form arrays. PV cells can be of various types which include Mono crystalline silicon cells, Poly crystalline silicon cells, Poly crystalline silicon thin film, Gallium arsenide cells and Thin film PV cells. A PV cell is shown in Figure 2.5.

Figure 2.6. PV cell

b. Charge controller; since the brighter the sunlight, the more voltage solar cells produce, the excessive voltage could damage the batteries. A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array rises, the charge controller regulates the charge to the batteries preventing any overcharging. Most quality charge controller units have a three-stage charge cycle as followings: During the bulk stage of the charge cycle, the voltage gradually rises to the Bulk level (usually 25.6 to 26 volts) while the batteries draw maximum current. During this stage the voltage is maintained at bulk voltage level for a specified time (usually an hour) whiles the current gradually tapers off as the batteries charge up. After the absorption time passes, the voltage is lowered to float level (usually 25.2 to 25.5 volts) and the batteries draw a small maintenance current until the next cycle (Emad, 2013). Most multi-stage charge controllers are Pulse Width Modulation (PWM) types. The newer Maximum Power Point Tracking (MPPT) controllers are even better. They match the output of the solar panels to the battery voltage to insure maximum charge Ampere. The Charge Controller is installed between the Solar Panel array and the Batteries where it automatically maintains the charge on the batteries using the three-stage charge cycle described above. A typical charge controller is shown in Figure 2.6.

Figure 2.7 Solar charge controller

c. DC battery; the dc battery is basically the deep cycle type used to store electricity to provide energy on demand at night or on overcast days. Atypical deep cycle dc battery is shown in Figure 2.4.

Figure 2.8 Deep cycle DC battery

d. Inverter;

An inverter shown in Figure 2.8 is used to convert the direct current (DC) power produced by the PV module into alternating current (AC) power.

Figure 2.9 Solar Inverter

2.4 Related Literature Review.

In 1980, final year students of Obafemi Awolowo University took up the challenge to research and develop a yam pounding machine having studied the problems of the Harbert and Kenwood meshing machine. To their credit a design blue print was made and sent to Japan, and the first ever yam pounding machine was then fabricated and imported into the country but this machine was faced with the problem of its high cost, making it affordable to only the rich. However, some of these above mentioned deficiencies were improved on by Odior (2008) where he designed a pounding machine capable of producing a better homogeneous bond yam. In his design, the pounding chamber had two beaters with curved blades. The machine operated at a high speed and was not adequately ventilated resulting to the electric motor overheating hence having low durability.

Aghawegbehe and Olodu (2022) carried out research on design and construction of a wood-based modified yam pounder machine. The research was focused on the design and construction of a wood-based modified yam pounder machine. The authors asserted that the high cost of producing yam pounder machine using stainless steel and other metals posed great challenges in terms of efficiency and affordability. In their study therefore a yam pounder was produced from hardwood obtained from Oak tree which is a locally sourced material with a view to eliminating the tedious and laborious process of preparing pounded yam. The hardwood log of 220 mm long was turned to a diameter of 240 mm using wood lathe machine

Osueke (2010) improved on the design made by Odior by incorporating a steaming chamber inside the pounding machine. This design consists of mainly two chambers which were made of stainless steel and shafts. One of the chambers was used for cooking while the other chamber is used for the pounding.

Otegbayo et al. (2011) carried out physiological characteristics of different yams in Nigeria wherein they asserted that Yam (Dioscorea spp.) is the second most important root and tuber crop in Africa after cassava. Their study was carried out to determine the relationship between physicochemical properties of yam starch (amylose and amylopectin, swelling, solubility and water binding capacity) and the textural quality (stretchability, cohesiveness, adhesiveness, hardness) of pounded yam, a major food product in West Africa. In their methodology, Yam starch was extracted from six tubers each of Dioscorea alata and D. rotundata and their physicochemical properties were determined by standard methods. Pounded yam was prepared from the same set of tubers.

Olaoye and Oyewole (2012) reported that a machine for pounding yams and similar foods was developed by Makanjuola (1974) at the Department of Agricultural Engineering of University of Ile - Ife in Nigeria. It is capable of producing enough 'fufu' for eight adults in 45 seconds (UNIFEM, 19930.

Otegbayo (2021) carried out a technical report on the state of knowledge report on pounded yam in Nigeria. The research focus was on pounded yam quality and sensory attributes. The author asserted that physico-chemical composition of yam tuber such as the granule morphology, pasting properties, swelling, water binding capacity of yam starch, nutrient composition in terms of proximate, minerals, vitamins, and anti-nutritional factors (phytates, tannins, saponins and oxalates) in the yam tuber.

Ibhadode et al. (2020) carried out research on the development of a modular and sustainable yam pounding machine. The research work was focused on the design and production of a yam pounding machine which consisted of a shaft, electric motor, stainless steel, pot, yam beater or blade, pulley and the frame. appearance, and cost and corrosion resistance. A power requirement of 1hp was needed to drive the machine. However, an improvement was made on the size, making it more portable than the existing ones and the use of dampers to minimize vibration with better reliability and working efficiency. Performance of the machine was evaluated to its highest level of efficiency of 96% by pounding 3kg of cooked yam. The authors further classified yam pounding machines two types which are: Impact (Reciprocating) pounding and rotary (torque) pounding. The impact (reciprocating) pounding modes reciprocate in its operation. The mortar and pestle mode of pounding is classified under this class.

CHAPTER THREE

METHODOLOGY

3.1 MATERIALS

The materials required for the execution of the research in terms of the development of the proof of concept of a hybrid energy food warmer include the followings:

i. *Computer system* for typesetting and graphics detailing.
ii. *Workshop production tools* such as cutting machine, lathe machine, drilling machine, welding machine, electrodes, abrasive disks, paint.
iii. *Production materials and components* of the machine such as diodes, transistors, programmable board, temperature controller, switches, wires, solar gadgets.

3.2. Conceptual Design

Concepts of the yam pounding machines were considered and a choice was made out based on suitability of purpose and design variables that were considered using a decision matrix. Two concepts were significantly viable for consideration as follows;

3.2.1 Concept 1: Electric Yam Pounding Machine

The electric powered yam pounder shown in Figure 3.1. It comprises of a pounding bowl, electric motor as the prime mover, belt and pulleys and a yam beater which does the yam pounding action. It operates on the principle of a rotating action of the beater which then beats the cooked yam to its sticky dough inside the bowl.

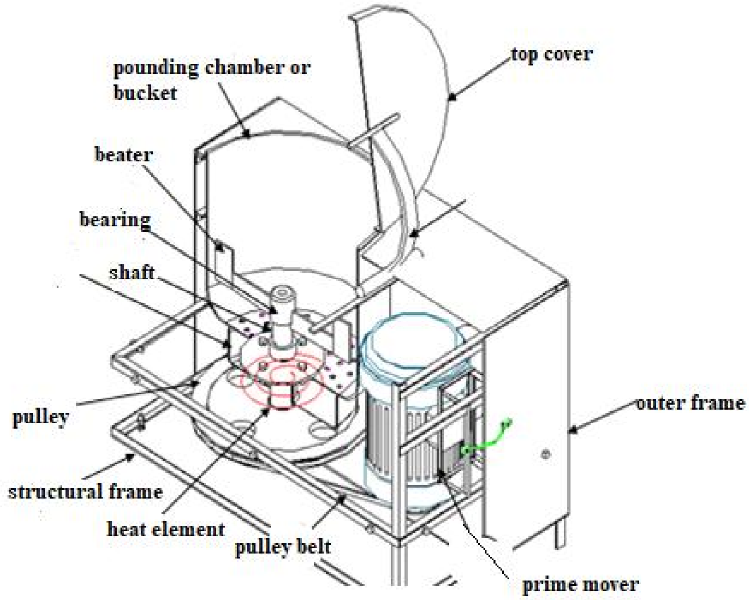

Figure 3.1 Electric yam pounding machine

3.2.2 Concept 2: Electric/Solar Powered Yam Pounding Machine

The concept 2 shown is a replicated of the concept but the incorporation of solar power components such as inverter, charge controller, solar battery and solar panel.

3.2.3 Concept Selection Through Decision Matrix

The decision matrix was used to select the most viable design amongst the two concepts based on some critical design inputs of the machines as shown in the Table 3.2. First the design inputs and considerations have to be itemized, tabulated and scaled on a decision matrix as shown in Table 3.2.

Table 3.4 Decision matrix for yam pounding machine concepts

Selection criteria	Weighting	Concept 2		Concept 1	
		Score	Total	Score	Total
Versatility of use	7	7	49	6	42
Low cost of Energy utilization	6	6	36	5	30

Low cost of production	5	4	20	5	25
Simplicity	4	3	12	4	16
Total			117		111

From the decision matrix in Table 3.2, the concept 2 which is the solar powered yam pounding machine polled the highest weighted score of 117 as against the electric yam pounder machine which had weighted score of 111 based on the design criteria considered. The concept 2 having the highest weight is therefore selected for detail design and fabrication.

3.3 Design Details/Analysis

I. Sizing of pounding bowl

A small family size of 5 is estimated as user of the proposed solar powered yam pounding machine. The pounding bowl is to contain the lumps of yam to be pounded and blade. The minimum inside diameter to be allowed for the bowl is estimated as 0.15m. An additional allowance of about 0.1mm to 0.2mm on both sides of the blade and wall to avoid `frictional contact between the blade and the bowl circumferential wall was also considered.

Considering the length of blade + allowance given = 0.15 + (0.0002 + 0.0002) = 0.1504m

Volume of bowl = 0.0015 = $\pi r^2 h$ = 3.142 x $(0.1504/2)^2$ x h

Therefore, height of bowl = 0.084m.

II. Electric motor selection for the pounding machine

For force equivalence of motor and pestle action, the kinetic energy is expressed as:

K.E=(IШ²)……………………………………………………………..…….(3.1)

where:

m = mass,

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

h = height,

I = mass moment of inertia = mk^2

k = radius of gyration

w = angular velocity.

The mass of the blade is density x volume

The density of the blade which is made of aluminum = $2700kg/m^3$

And the volume of the blade is the sum of its respective volume of its cross sectional area.

where the intended length, breadth and width of the horizontal column of the blade is = 0.15m 0.015m and 0.01m respectively.

Therefore, the volume of the horizontal column of the blade = 0.15 x 0.015 x 0.01m = 2.25×10^{-5}

For the two vertical columns, the respective length, breadth and width are 0.05, 0.015 and 0.01m. therefore the volume of the vertical columns is given as

2[0.05 x 0.015 x 0.01] = 1.5×10^{-5}

Total volume of the blade = $2.25 \times 10^{-5} + 1.5 \times 10^{-5} = 3.75 \times 10^{-5}m^3$

Therefore, the mass of the blade = density x volume = 2700 x 3.75 x $10^{-5}m^3$ = 0.10kg

K = 0.075m = (half the blade length)

Therefore, I = mk^2 = 0.10 x 0.075^2 = 5.625 x 10^{-4}kg-m^2

The impact load = the kinetic energy K.E i.e. 19.6 = 5.625 x $10^{-4}Ш^2$

$Ш^2$ = 19.6/5.625 x 10^{-4} and Ш = √34844 = 186.66rad/s

But Ш = 2πN/60. Hence, 186.66 = 2πN/60 and

N = 1782rpm

The torque to be generated by the blade is given as T= P x perpendicular distance s of line of action of the load.

s is assumed to be half the blade length, therefore;

T = 19.6 x 0.075 = 1.47Nm

The torque is related to the angular velocity through the following expression;

$T = \frac{Px60}{2\pi N}$ …………………………………………………….………..…. (3.2)

where:

P = Power required to drive the blade through the shaft and pulley

$1.47 = \frac{Px60}{2\pi.1782}$, making P, the subject of the expression

P = 1.47 x 2 x 3.142 x 1782/60 = 274 watts = 0.37watts

An electric motor of 0.5 watts will be selected for optimization and to make up for friction and other losses that might arise in the machine during operation.

III. Pulley design

The pulley system schematic is shown in figure 3.5., where c is the center to center distance

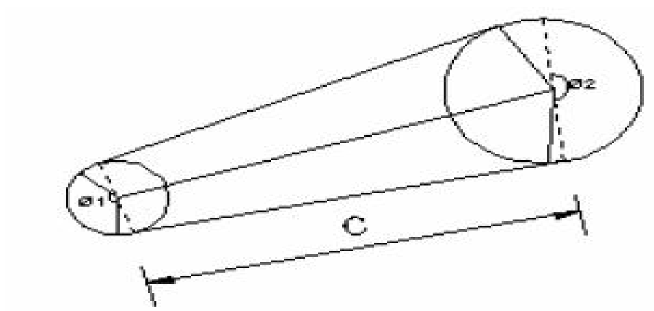

Figure 3.2 Pulley system

(i) The ratio of speed transmission to be x: y.= 3:1 for adequate speed reduction. This is necessitated for proper sizing of the driven pulley and avoiding unnecessary speed of the rotor

(ii) Coefficient of friction between belt (leather tanned) and pulley (Cast iron) is $\mu = 0.35$. The combination of the material for the belt and the pulley is necessitated for efficient function

(iii) Angle grooving of the pulley, is $\theta° = 40°$, for the best performance of belt.

(iv) Diameter of small pulley = D_s = 50mm (attached to electric motor as supplied)

(vi) Diameter of big pulley = D_l

From the relationship, the center distance, c between the two pulleys is taken as the larger of the value between

$\frac{3Ds}{2}+\frac{DL}{2}$ And c = D_L, [Deutschmann and Aron, 1985]

Therefore c = max ($\frac{3Ds}{2}+\frac{Dl}{2}$ and D_L)…………………………………....……. (3.3)

From Fig.3.15 above we have,

$\theta_1 = 180° - 2\sin^{-1} = (\frac{DL-Ds}{(\frac{2}{c})})$.. (3.4)

$\theta_2 = 180° + 2\sin^{-1} (\frac{DL-Ds)}{(\frac{2}{c})})$ .... (3.5)

From the relationship,

D_L= 3Ds

Therefore, D_L = 3×50=150mm

Where D_L =150mm is the diameter of the large pulley, and Ds is the diameter of the smaller pulley.

The centre distance, C between the two pulleys is taken as the larger of the value between $\frac{3Ds}{2}+\frac{DL}{2}$ and C = D_L,

Therefore C = max ($\frac{3Ds}{2}+\frac{D1}{2}$ and D_L)

That is c = ($\frac{3(50)}{2}+\frac{150}{2}$ or 150),

Therefore, c = (150 or 150) = 150 mm.

From Fig. 3.15 we also have,

$\theta_1 = 180° - 2\sin^{-1} = (\frac{DL-Ds)}{(\frac{2}{c})}) = 180^0\ 2\sin^{-1} 0.3333 = 141^o$

$\theta_2 = 180° + 2\sin^{-1} (\frac{DL-Ds)}{(\frac{2}{c})}) = 180^0 + 2\sin^{-1} 0.3333 = 219^o$

IV. Shaft design

For the Shear stress on the shaft:

Shearing stresses are induced in the shaft due to the fact that it is subject to a torque or twisting moment. The shear stress produced in the shaft is given as:

$\tau = \frac{Tr}{J}$ .... (3.6)

where

τ = shear stress (MPa)

T = twisting moment (Nm)

r = distance from center to stressed surface of the shaft in (mm)

J = "polar moment of inertia" of cross section (mm^4)

The maximum moment on the Shaft

The maximum moment in the circular shaft can be expressed as:

$T_{max} = \frac{\delta j}{R}$ ……………………………………………………………….....….... (3.7)

where

T_{max} = maximum twisting moment (Nm)

τ_{max} = maximum shear stress (MPa)

R = radius of shaft (mm)

J = the polar moment of inertia on the shaft can be expressed as

$= \frac{\pi R^4}{2} = \frac{\pi D^4}{32}$ for round solid shaft or $\frac{\pi(do^4 - di^4)}{32}$ for hollow shaft……………..….. (3.8)

d_o and d_i are the outer and internal diameter of the hollow shaft respectively

Substituting for J in equation 3.12, we have

$T_{max} = \frac{\pi R^4 \tau_{max}}{2R} = \frac{\pi R^3 \tau_{max}}{2} = \frac{\pi D^3 \tau_{max}}{16}$ ………………………………………... (3.9)

But for a hollow solid shaft, equation 3.14 and 3.15 are expressed in terms of the outside and internal diameter of the shaft as follows,

$J = \frac{\pi(R^4 - r^4)}{2} = \frac{\pi(do^4 - di^4)}{32}$ ………………………………………,……… (3.10) and,

$T = \frac{\pi}{16}\ x\ \frac{\tau_{max}[do^4 - di^4]}{d}$………………………………………………… (3.11)

R = d_o/2, and r = di/2

Note: D = diameter of shaft and it is given as

$1.72\ (\frac{T_{max}}{\tau_{max}})^{1/3}$ …………………………………………..………… (3.12)

But recall, T = 1.47Nm as calculated (refer to chapter two; torque calculation).

If an allowable shear stress is taken (31 to 47MPa for alloy cast steel and iron)

45MPa. is used. Inputting value of T and τ into equation 3.12, then:

$D = 1.72(\frac{1.47\ x\ 1000}{31})^{1/3}$ = 6.2mm say 1.2cm.

V Torsional deflection of the shaft:

The angular deflection of a torsion solid shaft can be expressed as

$\theta = \frac{584LT}{GD^4}$ ……………………………………………………………..……. (3.13)

where;

θ = angular shaft deflection (degrees)

L = length of shaft =

T = torque transmitted by shaft in

G = modulus of rigidity (MPa)

D = diameter of shaft

$= (5 \times 8 \times 4 \times 10 \times 1.47)/\ 210 \times 10^3 \times 10^4$

$= 0.0112(1)^4 = 0.0112^0$

VI. Bearing selection

Evaluation of some governing conditions guided the selection of the bearing used for supporting the rotating shaft of the yam pounder. The conditions evaluated includes the followings

a) First was the selection of rolling contact bearings over sliding contact bearings due to the former's advantages that were closely desired for the nature of the machine crucial amongst which included; Its low starting and running friction within the desired low speed, Its ability to withstand momentary shock loads, accuracy of shaft alignment and low cost of maintenance.

b)The desired speed to be transmitted from the shaft as supplied from the motor is desired to be low and far less than 2000rpm

c) The bearings required needed to have ability to bear load at this speed

d) The minimum static and dynamic load rating of the bearing has to exceed the bearing load of the shaft.

The above information alongside other conditions as coefficient of friction and bore diameter of the bearing, which are calculated and or matched from reference and manufacturers manual gives a better selection from series of potential bearing for the nature of machine. Though for purpose of studies, the mathematical analysis of the above mentioned parameters are elaborated. The alternative method of reading off from reference manual as shown in the appendix six of this material was adopted for this work for reason of timely completion of the project.

"From appendix 6 the appropriate bearing is selected based on output speed, bore size, static load, and dynamic loads and bearing load of shaft.

The Dynamic equivalent load for rolling contact bearings (DEL) was put into consideration. It is the constant stationary radial load (in case of radial ball or roller bearings) or axial load (in case of thrust ball or roller bearings) which, if applied to a bearing with rotating inner ring and stationary outer ring, would give the same life as that which the bearing will attain under the actual condition of load and rotation (Khurmi et al 2005).

Denoted by W and for the radial and angular contact bearings under combined constant radial load W_R and constant axial or thrust load W_A is given by the expression below

$$W = X.V.W_R + Y.W_A) \qquad 3.14$$

Where;

V = A rotation factor = 1 for all types of bearings when the inner race is rotating

And the values of radial load factor X and axial or thrust factor Y for the dynamically loaded bearings may be taken from references or appendix two of this literature.

Dynamic load rating for rolling contact bearings under variable loads DLR

This denoted by C, is the constant stationary load (in case of radial ball or roller bearings) or constant axial load (in case of thrust ball or roller bearings) which a group of apparently identical bearings with stationary outer ring can endure for a rating life of one million revolutions (which is equivalent to 500 hours of operation at 33.3 rpm) with only 10 parent failure. [Khurmi et al, 2005]

It is given as

$C = W (L / 10^6)^{1/k}$ …………………………………………..………..….3.15

Where

W= equivalent dynamic load

L= service life rating of the ball or roller bearing

The relationship between the life in revolution L and the life in working hours L_H is given by

$L = 60N.L_H$ revolutions where N I the speed in rpm

k = 3, for ball bearings and 10/3 for roller bearings

Having evaluated all factors from calculated, working condition and references, ball bearings were found suitable and used for the measuring machine.

In selecting the most suitable ball bearing, the basic dynamic radial load was multiplied by a service factor (K_s) to get the design basic dynamic radial load capacity. The service factor for the ball bearings is shown from references or appendix three of this literature. After determining the design basic dynamic radial load capacity, the selection of bearing was made from literature and manufacturers reference catalogue. Find reference in appendix three of this literature for the basic static and dynamic capacities of various types of ball bearings.

VII. Solar Power Components Specification

i. Solar panel specification

Solar panel capacity; this is the watts rating of the photo-voltaic cell. The PV cell is required to charge the DC battery in watts-hour. The charging capacity is expressed as

$$P_p = \frac{Battery\ energy}{charge\ time} \quad (3.16)$$

ii. Calculation of battery size

The capacity of the batteries is calculated by multiplying the daily total direct current (DC) energy requirement of the PV system including loads and system losses expressed in Ampere-hour (Ah), by the number of days of recommended reserve time. The load requirement in watts of the system include the electric motor of the yam pounder and indicator light.

In order to prolong the life of the battery, it is recommended to operate the battery using only 80% of its required capacity. Therefore, the minimal capacity of the batteries is determined by dividing the required capacity by a factor of 0.8.

$$\text{Useable battery capacity (Ah)} = \frac{\text{design load (Ah/day)}}{\text{days of autonomy}}\ x\ \frac{1}{\text{maximum depth of discharge fraction.}} \quad (3.17)$$

$$\text{Design battery capacity (Ah)} = \frac{\text{Useable battery capacity}}{\text{Useable fraction of capacity available.}} \quad (3.18)$$

The number of batteries is then obtained by dividing the design battery capacity with the choice of battery capacity.

iii. Design of PV array sizing

Number of solar panels = $\frac{Design\ month\ daily\ load\ (KWh)}{Power\ rating\ of\ pannel}$.

iv. Calculation of inverter size

The nominal power of the inverter should be smaller than the PV nominal power. This depends on the inverter optimum power ratio which invariably depends on the regional climate, the inverter efficiency curve and the inverter/PV price ratio. Therefore, the inverter nominal power is computed as;

Inverter nominal power(KW) = Chosen PV array power (KW) x Inverter safety factor (3.19)

The purpose of over sizing of the inverter is to compensate for unexpected long cloudy periods.

v. Solar Charge Controller Sizing

The solar charge controller is typically rated against Amperage and Voltage capacities. Selection of solar charge controller depends on the voltage of PV array and batteries. The charge controller is rated by the output Amperage that they can handle, not the input current from the solar panel array. To determine the output current that the charge controller will have to handle we use the very basic formula for power (watts), which is:

$V_{in} = V_{DC} = 24V$

$$I_{in} = \frac{Ppeak}{Vdc} \quad (3.20)$$

$$I_{out} = \frac{P_{out}}{V_{out}} \quad (3.21)$$

where:

$V_{out} = V_{DC} = 24V$

P_{out} is wated in watts

3.4 Bill of Engineering Materials and Evaluation (BEME)

The bill of engineering materials and evaluation of the solar powered yam pounding machine is presented in Table 3.3

Table 3.3 Bill of Engineering Materials and Evaluation of Solar Powered Yam Pounding Machine

S/No	Component	Quantity	Capacity	Unit Cost	Total Cost =N=
1	Shaft	1			5000
2	Big Pulley	1			5000
3	Small Pulley	1			4000
4	V-Belt	1			1500
5	Bearing	1			4000
6	Electric Motor	1	1hp		105000
7	Blade	1			2000
8	Bowl	1			5000
9	Angle bar for frame work	1.5meter			7000
10	Angle bar for frame work	1.5meter			10000
11	Galvanized sheet for the casing	1roll			20000
12	Welding electrodes	40			3000
13	Solar panel	1	900w		
14	Solar battery	sum			
15	Inverter	1m			
16	Charge controller				
17	Miscellaneous				30000
19	Labor				
	TOTAL				

The graphical view of the fabricated solar powered yam pounding machine is shown in Figure 3.4.

3.5 Testing of the developed proof of concept of solar powered yam pounding machine.

The machine was completed and tested for evaluation.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The results of recorded from the testing of the solar powered yam pounding machine in comparison with the use of alternating current powered yam pounding machine is presented in Table 4.1.

Table 4.1 Pounding time for solar and alternating current (AC) current for pounding

Mass of yam (kg) pounded	Time (min) to finish pounding using AC current.	Time (min) to finish pounding using solar power
0.2	1	1.15
0.4	1.20	1.50
0.6	1.45	2.
0.8	1.57	2.10
1	2.05	2.35
1.2	2.15	2.51

From the Table 4.1 it is deduced that increasing amount of cooked yam to be pounded results in elongated time for the pounding action for both the alternating current (AC) and direct current (DC) power systems. The effect of increased time to pound yam as the quantity of yam increases is observed to be higher with the use of DC power compared with the use of AC power as observed in the graph in Figure 4.1. the red curve for the DC is observed to be above the blue curve, indicating higher values of increased time. This may be due to the slow dissipation of energy from the battery compared to that of AC. As the DC battery supplies energy to the electric motor, its energy depletes and its discharges resulting in fluctuating power dissipation that affects the energy supplied to the pounding machine. On the average, it takes the DC battery

2 minutes to finish pounding an average amount (0.7kg) while it takes the AC powered pounder 1.47 minutes to finish pounding the same amount cooked yam. The insignificant difference in time between the operation of the AC and DC powered yam pounder highlights the effective functionality of the solar powered yam pounding machine. The battery charging and depletion were dependent on the sun irradiation as well as the usage level respectively of the system.

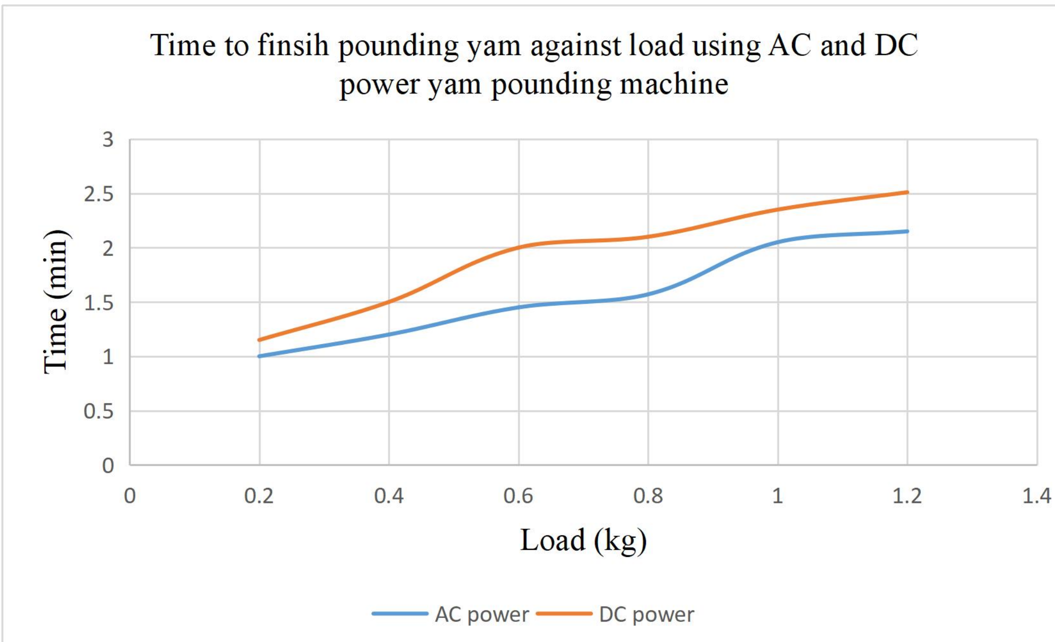

Figure 4.1 Graph of Time to finish pounding against mass of load of yam using solar Dc and AC power

4.1.2 Machine throughput capacity

The machine throughput was estimated as;

$$\text{Machine throughput capacity (kg/hr)} = \frac{\text{Average mass of feed extruded (kg)}}{\textit{average time taken to extrude (hr)}} \qquad 4.1$$

Average feed output = 0.7kg in 2 minutes

Therefore; in 1hr, machine will produce $\frac{60}{2}$ x (0.7) kg = 21kg

Therefore machine throughput capacity = $\frac{21kg}{1hr}$ = 21kg/h

Pounding efficiency = load output $\frac{Average\ load\ output\ (kg)}{Load\ input\ in\ (kg)}$ x 100 4.2

where;

Load input = 10kg

Average load output = 9.75kg

Therefore efficiency of pounder = $\frac{9.75}{10}$ x 100 = 97.5%.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This project was carried out to achieve its aim and objectives of developing a mechanical yam pounding machine, incorporating solar power components to power it in the absence of mains electricity and carrying out a comparative test between an alternating current powered yam pounding machine and a solar powered yam pounding machine. The research was able to determine the time to finish pounding given amount of cooked yam when using an electric and solar powered yam powered pounding machines. The machine could pound 0.7kg of yam in 2 minutes, while it takes longer time for manual process of yam pounding. Result from the testing of the machine show that the machine performed faster, efficiently and hygienically better than the manual method of pounding and more versatile in use compared to the conventional AC powered yam pounding machines.

5.2 Recommendations

Following the development and testing of the solar powered yam pounding machine, the following recommendations are made:

1) Further research should be carried out to produce a hybrid powered yam cooking and pounding machine.

2) Research should be explored in the development of smart yam pounding machines which can use smart sensors to carry out autonomous operations.

REFERENCES

Adejumo BA, Okundare RO, Afolayan OI, Balogun SA (2013). Quality attributes of yam flour (Elubo) as affected by blanching water temperature and soaking time. Int J Eng Sci 2:216–221.

.

Aghawegbehe K, Olodu, D (2022). Design and construction of a wood-based modified yam pounder machine International Journal of Energy Applications and Technologies 9(1) [2022] 22-30.

Ayodeji, S.P, Olabanji, O.M, Adeyeri, M.K (2012). Design of a process plant for the production of poundo yam. International Journal of Engineering (IJE), Volume (6): Issue (1): 2012.

Ibhadode Oisehoemomen, Aniekan Essien1 and Adedoyin Adesuji. (2020). Development of a Modular and Sustainable Yam Pounding Machine. Global Journal of Engineering SciencesISSN: 2641-2039 DOI: 10.33552/GJES.2020.06.000626.

International Institute of Tropical Agriculture, (IITA) Root and Tuber Systems, Internet: www.iita.org, 2008 [May 25, 2010].

Ikenna, F. (2014). The design and performance evaluation 0f a yam cooking and pounding machine suitable for domestic use in Nigeria. A project submitted in partial fulfillment of the award of masters of engineering, (m.eng) in the mechanical engineering department faculty of engineering university of Benin.

Kearsley, M. W. and Sicard, P. J. 1989. The chemistry of starches and sugars present in food. In Dobbing, J. (ed.). Dietary Starches and Sugars in Man: A Comparison. Springer, London, pp. 1-34.

Liu et al (2020) Design of feed screw conveyorJ. Phys.: Conf. Ser. 1601 062005.

McIntire, D. D., Ho, C. and Vogel, H. J. 1990. One-dimensional nuclear magnetic resonance studies of starch and starch products. Starch/Stärke 42:260-267.

Noda, T., Tsuda, S., Mori, M., Takigawa, S., Endo, C.-M., Hanashimoto, N. and Yamauchi, H. 2004. Properties of starches form potato varieties grown in Hokkaido. J. Applied Glycoscience 51:241-246.

Odior, A.O and Orsah, E.S. Design and Construction of A Yam Pounding Machine", International Journal of Natural and Applied Sciences, 4(3): 319-323, 2008

Ogiemudia et al, (2016). Comparative Analysis of Yam Pounding Machine and the Traditional Pounding Method. International Academic Journal of Innovative Research Vol. 3, No. 12, 2016, pp. 1-12.

Omohim et al, (2018). Study of the proximate and mineral composition of different Nigerian yam chips, flakes and flours. J Food Sci Technol (January 2018) 55(1):42–51 https://doi.org/10.1007/s13197-017-2761-y

OTEGBAYO, B Oluyinka ORONIRAN, Olabisi FAWEHINMI, Adebamiji AYANDIJI, (2018). A Review on Yam. It's Quality and Sensory Attributes. Iwo, (Nigeria). RTBfoods Project Report, 13p.

Otegbayo et al, (2011). Physicochemical properties of yam starch: Effect on textural quality of yam food product (pounded yam). Journal of Food, Agriculture & Environment Vol.9 (1): 1 4 5 - 1 5 0 . 2 0 1 1

Raji, O and Kazeem, O (2007). Development of a Yam Pounding Machine. Article in Ama, Agricultural Mechanization in Asia, Africa & Latin America · September 2007.

Yohanna, M.Z (2018). Design and Modification of a Yam Pounding Machine. International Journal of Science and Research (IJSR) ISSN: 2319-7064. ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426